Weight Estimation without Waiting:

Design, Development and Testing of a Mobile Application to Measure the Length and Estimate the Weight of New Zealand Children for Advanced Paediatric Resuscitation.

A thesis submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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Abstract

Background

Weight estimation is critical in paediatric resuscitation as the time taken to weigh a child could directly influence their survival and quality of life. Unfortunately, the weight estimation techniques used in New Zealand are not accurate which, impacts the complexity of prescribing medication doses and selecting equipment size used in treatment during paediatric resuscitation.

Aim

Mobile technology could streamline the process of weight estimation and paediatric resuscitation. Therefore, this research aimed to design, build, test and evaluate a mobile application that will estimate the weight of NZ children in varied environments using augmented reality on a mobile device. Weight estimates using the device aim to be within 10% of the child's actual weight in 75% or more instances.

Methods

An adapted design science approach was utilised that included investigation of existing solutions, application design, development, software testing (functional testing with preliminary exploratory testing, user observation, user testing via processes using the "think aloud method"). Regression modelling/equations are developed, tested for fit and compared with existing weight estimation techniques endorsed in NZ. The accuracy was assessed using MPE, limits of agreement and the proportion of weights within a 10%, 20% and 30% of actual weight. The distribution of errors was examined and limitations and future work are specified.

Findings

The Weight Estimation without Waiting (WEWW) mobile application was designed, developed, tested and evaluated. Even though the WEWW application outperformed (MPE 1.1, SD 23.2) the New Zealand Resuscitation Council (NZRC) (MPE 21.6, SD 16.7) and St John (MPE 18.9, SD 16.9) the accuracy of the WEWW application could be improved. For example, by either transforming the data using distribution of error to improve regression or machine learning models. Users were positive about the application and believe that it is easy to use and would make their weight estimates more reliable. However work still needs to be completed around regulation of the application and accuracy may be improved further in the future by more in-depth analysis of workflows and medication doses to support weight estimation.

Conclusion

The WEWW application provides a novel method to estimate the weight of children during resuscitation. Even though the WEWW application currently outperforms weight estimation methods endorsed in NZ it has the potential to become even more accurate after further, post-doctorate work around the further development of machine learning and the user interface.

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Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), not material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or institution of higher learning."

Student Signature

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Abbreviations

The following list of abbreviations is used throughout this thesis. To improve readability, they are also defined in the text the first time that they appear in each chapter.

2D	Two dimensional
3D	Three dimensional
AC	Acceptance criteria
AED	Automated external defibrillator
AF	Atrial fibrillation
AI	Artificial intelligence
ALS	Advance life support
APLS	Advance paediatric life support
AR	Augmented reality
AUTEC	Auckland University of Technology Ethics Committee
BLS	Basic life support
BMI	Body mass index
BNFC	British National Formulary for Children
CDC	Centre for Disease Control
cm	Centimetre
CPR	Cardiopulmonary Resuscitation
CPU	Central processing unit
DA	Dispatcher assisted
DA-CPR	Dispatcher assisted CPR
DHB	District Health Board
DLT	Direct linear transformation
DSR	Design science research
EBP	Evidence based practice
ECG	Electrocardiogram
ED	Emergency Department
EMR	Electronic medical record
EXIF	Exchangeable Image Format
FDA	Food and Drug Association
GP	General Practitioner
GPS	Global positioning system
GUI	Graphical user interface
HSV	Hue, saturation value
H-DSR	Heavner's design science research method
ITFO	International Taskforce for Obesity
JBI	Johanna Briggs Institute
Kg	Kilograms
LoA	Limits of agreement
LoG	Laplacian of Gaussian Filter (used in edge detection)
ML	Machine learning
mm	millimetres
MMC	Mātauranga Māori Committee
MPE	Mean percentage error
NIASRA	National Institute for Applied Statistics Research Australia
NZ	New Zealand
NZRC	New Zealand Resuscitation Council
OHCA	Out of hospital cardiac arrest
PhD	Doctor of Philosophy
PPV	Positive predictive value
PRIME	Primary Response in Medical Emergencies
SMS	Short message service
T1	Triangle One
T2	Triangle Two
T1	Triangle Three
TAM	Technology Acceptance Model
UK	United Kingdom
USA	United States of America
WEWW	Weight Estimation without Waiting (application designed in this study)
WHO	World Health Organisation

1 Chapter One – Introduction

1.1 Introduction

Imagine a child is dying, and you are providing emergency care. The environment is crowded, noisy and you need to make many lifesaving decisions within 60 seconds. Everyone in the team is waiting for a vital piece of information from you – the weight of the child.

What would you do – estimate?

In this situation, I have estimated the child's weight and made calculations of equipment size and drug doses derived from that estimate. I am a registered nurse in New Zealand (NZ) with over 20 years of practice experience and have worked in many areas where children present including community, general practice, paediatric emergency nursing and the local ambulance service. For eight years of my career, I worked in a busy national children's Emergency Department (ED) which saw over 33,000 children each year.[1] Common presentations included situations where using a weight estimate allowed the initiation of care for a child who was too unwell to be weighed.

Resuscitation is often referred to as the process of restoring life.[2] Generally, resuscitation is associated with providing Cardiopulmonary Resuscitation (CPR). However, in practice, it often takes on a broader definition, meaning where a patient requires immediate care (Australasian Triage Category One[3]). During paediatric resuscitation, there are many decisions to be made, including an early calculation of a child's weight and application of this information to treatment. For example, in the medication administration process, many decisions are required:

- Select the appropriate weight estimation technique
- Recall formulae or processes
- Calculate the weight estimate
- Document the weight estimate
- Calculate drug doses for that weight
- Prepare drug doses
- Administer these

Correct decisions (including estimation of weight) are vital to ensure the appropriate medications, doses and routes are selected during resuscitation. Furthermore, these decisions are time-critical, and any errors threaten survival and the quality of life. In a study of medication errors during paediatric pre-hospital cardiac arrest, 34% (n = 125/360) were related to dose errors.[4] In many cases these could have been directly influenced by weight estimation. Alongside this, the resuscitation environment is often crowded, fast-paced and decision-dense, which further increases the chances of errors.[5] Similarly, staff fatigue, resource availability and the variance in age and size between children also increase the risk of error. In other words, the influences on weight estimation are multifactorial[6] and understanding and streamlining resuscitation processes may assist in alleviating the risk of errors. This research will go on to explore how mobile technology could help to streamline weight estimation during paediatric resuscitation.

One could argue that resuscitation aids, such as tables and checklists already reduce cognitive loading and decrease error[5-7] making certain aspects or resuscitation easier to manage.[8] For example, a step by step process can decrease the cognitive load of clinicians. However, resuscitation requires the ability to adapt to the changing needs of the patient which can make pre-empting every aspect, situation or presentation challenging. What this means in practice is that, checklists can be a useful guide but completing every step may not occur. Introducing mobile technology that streamlines processes could ensure that all steps are included and therefore the optimal treatment is given during paediatric resuscitation.

This chapter will explore my own experience of working in the paediatric resuscitation environment as both an experienced registered nurse in a dedicated paediatric ED and an ambulance officer in the prehospital emergency care setting. The chapter presents the concept of weight estimation in paediatric resuscitation and details my prior research on this topic up until the beginning of this PhD. After this, the concept of using mobile technology to enhance weight estimation in paediatric resuscitation will be introduced.

1.2 Problem Statement

During paediatric resuscitation, the inaccurate weight of a child could contribute to ineffective medication dose and equipment choice.[9] In many situations weighing a child could prolong the time to treatment and therefore decrease their chances of survival. For example, the longer it takes to administer adrenaline (dose based on weight) during paediatric cardiopulmonary the chance of survival for that child decreases.[10-12] To minimise the time to treatment weight estimates are commonly used worldwide during resuscitation.[13] In New Zealand, the currently endorsed weight estimation techniques have been in use for many years and are not accurate for around half of the children.[14-17] In practice, the poor accuracy of existing weight estimation methods has led to ad-hoc changes to a weight estimate by healthcare professionals to compensate for the inaccuracy of weight estimates.

1.3 Proposed Solution

The solution investigated in this thesis is to design, build and test a mobile application that can remove the subjective bias introduced by ad-hoc changes to existing weight estimates. A more detailed research aim is shown in Section 1.9 of this chapter.

1.4 Research Motivation

In resuscitation, a weight estimate is often used to calculate body surface area, medication doses and equipment size which then allows clinicians to give the appropriate treatment[17, 18] and is a critical area that needs improvement during paediatric resuscitation. While research suggests that length-based weight estimation methods are more accurate,[16, 19-22] in practice, I found that staff chose the less accurate age-based methods of weight estimation, such as the Advanced Paediatric Life Support (APLS) formula which is endorsed by the NZ Resuscitation Council (NZRC). Furthermore, most staff members that I worked with seemed to believe that the APLS formula would underestimate the weight of children. From my experience, during a resuscitation staff would calculate the weight estimate using the APLS formula, acknowledge the inaccuracy and exclaim, “They look heavier than that; let’s add a bit”.

NZ guidelines for weight estimation exist, such as the use of the APLS formula;[18] however, this formula may not be accurate for NZ children as it has remained static for over 25 years while our population has continued to evolve in this timeframe. The first publication I have found in literature searches that refers to our current APLS formula is a 1995 case study of a paediatric resuscitation in the United Kingdom (UK) journal called Accident and Emergency Nursing.[23] This article, in turn, refers to a 1993 textbook called “Advanced Trauma Life Support For Physicians”[24] however, I have been unable to locate a copy of this textbook.

The APLS formula was derived from data collected from overseas populations, making the application of the APLS formula to the diverse NZ population difficult. Early evolution of the APLS formula seems to have occurred in the UK and United States (USA) and it is unclear exactly how this formula was derived or what population the original height and weight data belonged to.[23] Interestingly, the NZ Growth Charts and World Health Organisation (WHO) Growth Charts that are both commonly utilised in NZ healthcare are also not based on NZ dataset.[25] Which begs the question — with the current growth charts and weight estimation techniques based on overseas samples, are these processes giving an accurate representation of NZ children?

The two areas that stood out in my experience of weight estimation in both the hospital and prehospital environment were the impact of the variable conditions where weight estimation is performed along with the inaccuracy of weight estimation methods used in NZ.

1.4.1 The resuscitation environment

A common practice during hospital resuscitation is to individualise the environment to the needs of staff and the patient. As an example, the bed may be moved to allow for procedures and staff or family needs. In practice, these needs can change in an instant and for this reason the resuscitation environment needs to be versatile. This versatility makes using measurements to calculate the size of a child difficult as distances to objects and the child can quickly move and change position or angle.

Similarly, the ambulance environment and fleet in NZ are variable, so obtaining measurements to estimate weight can be challenging. The 2018 Annual Report for St John NZ (New Zealand's largest ambulance service provider) records attendance at 395,230 "emergency incidents" over twelve months, alongside 81,464 "non-emergency incidents", with 702 ambulances throughout NZ available to respond.[26] Searching Google for the term "NZ Ambulance Service fleet" revealed a myriad of ambulance designs and purposes. The search included ambulances donated or purchased in the last five years, while the St John Report spoke of rolling out "Gen 2" ambulances in 2018, with "Gen 3" coming in 2019.[26] A search of Google images for "types of ambulances in NZ" illustrated this variety with the first twelve images including different makes, models and layout of ambulance in NZ.

St John NZ uses at least three models of stretchers which can be loaded onto ambulances, and each ambulance also carries two smaller, more simple, folding field-stretchers for use in multi-casualty incidents. Thus, any method used to estimate the weight of a child carried in an NZ ambulance, must be performed in an environment that is varied and continually evolving. Mobile technology must also be used to improve paediatric weight estimation and must prove to be useful in such individualised situations and dynamic conditions.

1.5 Weight Estimation

Weight estimation in paediatric resuscitation is not a new concept. Existing research has striven to determine fast, accurate and accessible methods of weight estimation in paediatric resuscitation. Worldwide, the methods for weight estimation fall into three main categories: age-based, length-based and other.[27] Table 1 illustrates that a consistent stream of research papers strives to evaluate weight estimation techniques or derive new methods to achieve precise weight estimation in varying populations. This also shows that until now the focus of most has been on mathematical formulae and measuring tapes. Research around using mobile devices or technology to determine weight in paediatric resuscitation is limited, and the literature review in chapter two of this thesis will elaborate on the extent of mobile technology use in resuscitation.

Table 1 - Outline of the evolution of weight estimation methods

Name	Year	Country	Limit	Derived from	Formula or estimation method	Notes
Age-Based Weight Estimation						
Oakley Tables[28]	1988		0 – 14 years	A	Tables	
APLS[29] **	1982	UK & USA	1 - 9 years	A	(age in years + 4) x 2	
Nelson's Formula[30]	1986	USA	3 months - 1 year	A	(age in months + 9) / 2	
			1 - 6 years	A	(2 x age in years) + 8	
			7 - 12 years	A	((age in years * 7) - 5) / 2	
Leffler[31]	1997	USA	< 1 year	A	(2 x age in years) + 10	Original study tested children
			1 - 5 years	A	age (in months)/2 + 4	≤ 5 years
Shann's Formula[17]		PI	1 - 9 years	A	(2 x age in years) + 9	
			10 - 14 years	A	3 x age in years	
Theron's Formula[17]	2005	NZ	1 - 10 years	A	exp(2.20 + 0.175 x age in years)	
Argall's Modification[32]	2003	UK	1 - 10 years	A	(age in years + 2) x 3	
			< 1 year	A	(age in months + 9) / 2	
Best Guess Method[33, 34]	2007	Australia	1 - 4 years	A	(2 x age in years) + 10	
			5 - 9 years	A	4 x age in years	
Luscombe & Owens	2007	UK	1 - 10 years	A	(3 x age in years) + 7	
CWAR[35]	2011	China	1 - 6 years	A	(3 x age in years) + 5	Limited age range
ARC / NZRC[18]	2016	NZ	10 - 14 years	A	3.3 x age in years	
St John Ambulance [36]	2016	NZ	10 - 14 years	A	3 x age in years	
			< 1 year	A	(age in months + 9) / 2	
Park[37]		Korea	1 - 4 years	A	(2 x age in years) + 9	
			5 - 14 years	A	(4 x age in years) - 1	
Length-Based Weight Estimation						
Broselow Tape[38]	1987	USA	Height of 46 cm – 123 cm	H	Measuring Tape	
Lo Tape[39]	1995	Hong Kong	Not Stated	H	Measuring Tape	Derived from Broselow-Luten Tape
Malawi Tape[40]	1999	Malawi	Height 45 – 130 cm	H	Measuring Tape	4 – 16 kg
Kloeck Tape[41]	2000	SA	Not Stated	H	Measuring Tape	Secondary source only
PREM Tape[41]	2005	Not Stated	Not Stated	H	Measuring Tape	
Sandell Tape[41]	2004	UK	Not stated	H	Measuring Tape	
Mercy Tape[42]	2013	USA	2 – 16 years	H	Measuring Tape	
Other Weight Estimation Methods						
Hanging Leg Weight[43]	1990	USA	Children > 10 kg	O	Hanging Leg Weight	
Clothing Label Size[44]	2012	UK		O	Clothing Label Size + formula	

Finger Counting[45, 46]	2014	Canada	1 – 9 years	O	Finger Counting	
Mid Arm Circumference[47, 48]				O	Mid arm circumference	
Multi-Variable						
DWEM[49]	1986	USA	1 – 14 years	H, BH	Tables	
Pawper Tape, Pawper XL Tape[50]	2017	SA		A, H, O	Paper Tape, Pawper XL Tape	
Britnell Tables[14]	2016	NZ	5 - 10 years	A, G, E, H, BH	Tables	Limited age range

** Used currently by the NZRC[18] and St John Ambulance[36] in New Zealand.

Countries: NZ = New Zealand, SA = South Africa, PI = Pacific Islands, USA = the United States of America, UK = the United Kingdom

Derivatives: A = Age, G = Gender, H = Height, E = Ethnicity, BH = Body Habitus, O = Other.

Although standardised procedures for weighing a child and estimating weight exist, the use of these appears inconsistent amongst healthcare workers. For example, one study which investigated the prevalence of weighing children in resuscitation[51] reported that even though scales were built into the bed, the rationale for undocumented weight was varied, for example, not zeroing scales or extra items on the bed at the time of use. This highlights that external environmental factors such as these can impact the ability to weigh a child accurately during resuscitation.

It is also worth noting that the reasons why clinicians choose a weight estimation method or make the decision not to stop resuscitation and weigh a child is not clearly documented in the literature and is an area which requires further research.

1.6 The need for weight estimation in NZ

Weight estimation in resuscitation is a common practice in emergencies worldwide, however, recent research has looked at including demographic characteristics to increase the accuracy of weight estimation.[52] Furthermore, only two of these methods have been specifically designed to include the multi-ethnic nature of NZ children.[14, 16, 17]

The NZRC advises clinicians on current weight estimation practice in NZ. At the inception of this research the 2010 NZRC resuscitation guidelines[53] were in force and showed no recommendation for weight estimation other than age-based weight estimation methods. In 2016, these guidelines were updated and they then recommended that for non-obese children the estimation of weight can be calculated using length (height) or age.[18] However, for obese children, the NZRC recommends weight estimates only based on height. Interestingly, the NZRC guidelines do not define what is considered obese or give any guidance on which form of length-based weight estimation to use for obese children.[18] Therefore, any difference in perception of obesity could influence the accuracy of weight estimation techniques and increase the risk of error in the calculation of drug dose or equipment size.

Interestingly the NZRC guidelines for advanced paediatric life support were updated in 2016, yet the APLS formula remains the same as in previous guidelines. Furthermore, the APLS formula was first published more than 20 years ago[24] and the same formula is still in use today. Current research on the accuracy of the APLS weight estimation formulae shows that the estimated weight of Auckland children aged 5 to 10 years is within 10% of their actual weight in only 40% (n = 397) of children.[16] This means that over half of the children undergoing resuscitation based on the NZRC guidelines could have received inaccurate doses of medication or non-optimal equipment size.

1.7 Prevalence of Weight Estimation in Paediatric Resuscitation

The prevalence of weight estimates in comparison to actual weight measurement during resuscitation is minimally researched. A UK study completed in 1997[54] found that only 2% (n = 2/100) of children who were administered medication during resuscitation had their actual weight recorded before medication was administered. What this highlights is that 98% of children in this study had their weight estimated before receiving a medication dose based on their weight. A later study in the USA of children aged between 0 and 14 years found that even though scales were built into the resuscitation bed, only 65% (n = 145/231) had a measured weight recorded.[51] This study also found that the level of consciousness of each child at the time of triage influenced the use of weight estimation. Children who had a lower level of consciousness were more likely to have their weight estimated as opposed to being physically weighed as increasing the time to treatment by stopping to weigh a child is known to negatively impact survival.[8, 51]

Potentially 41,687 children require weight estimation to provide immediate care in NZ every year. Recent NZ ED utilisation statistics (Figure 1) have revealed an increasing number of visits by children per year.[55] While children under the age of 15 years make up about 25% of ED presentations it is unclear how much of the exact proportion of these children require resuscitation and are, therefore eligible for weight estimation. A 2009 study of NZ and Australian EDs suggested that 27% of children are categorised as Australasian Triage Category 1 or 2, which means that they are considered to be in life-threatening conditions.[56] This means that they require either immediate care or care within 10 minutes of presentation. If this prediction is applied to the 2014/2015 annual presentations of 154,396 per annum, 41,687 children may potentially need their weight to be estimated within NZ EDs each year. While parents may know the weight of some of these children, anecdotally, my experience shows a mismatch between parental knowledge of weight and the measured weight of a child. Furthermore, these statistics include presentations to District Health Board EDs and exclude prehospital presentations and those who initially present to their General Practitioner (GP) or local accident and medical clinics. This means that the use of weight estimation could be higher.

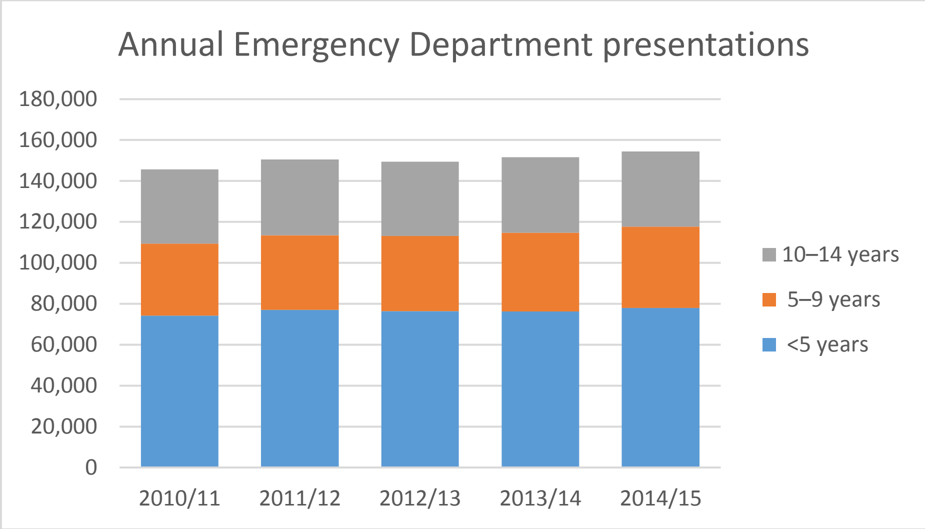


Figure 1 - NZ ED annual usage by children aged 0 - 14 years[55]

The increasing diversity of the NZ paediatric population may increase the risk of weight estimation becoming more ad-hoc. Considering the diversity of children along with the unknown aetiology of current weight estimation methods used in NZ, further tailoring of weight estimation to suit the unique characteristics of NZ children may reduce the risk of error, and is, therefore, an aim of this PhD research.

1.8 Risks of Inaccurate Weight Estimation

Inaccurate weight estimation could contribute to ineffective medication dose and equipment choice during resuscitation of a child.[9] For example, airway equipment of a smaller size can cause ineffective airway management, in my clinical experience choice of endotracheal tube that is too small caused air to leak around the tube, thus increasing the risk of aspiration, poor perfusion and death. Accurate and timely scaling of medication dose and equipment size is essential in paediatric resuscitation as it enables the provision of quality and safe care as directed by the NZ Health Strategy.[57] Scaling of treatment often relies on weight or derivation of body surface area from weight to determine resuscitation requirements.[18, 58] While measuring the actual weight of a child is considered “gold standard”, in paediatric healthcare, some situations require an alternative method for determining weight. As an example, if scales are not available, are challenging to utilise, or too much time is taken to weigh the child, it can impact survival or quality of life. In these cases, weight estimation can decrease the time to treatment and optimise resuscitation.[8, 16]

Most medication errors in the paediatric ED are related to dose errors,[58] and they are due to the complexity of medication regimes and the need for individualised calculation of doses. With weight-based medication dosing known to increase errors,[9] this risk is further compounded by the potential inaccuracies of weight estimation.[59] Furthermore, there is a nonlinear relationship between body mass and the pharmacokinetics of medications, particularly lipidsoluble medications, and this can lead to an inconsistent therapeutic effect.[9] For example, changes in organ function or development as children grow influence the efficacy and toxicity of medicines.[60] Although nonlinear techniques for calculating drug doses are available, such as, body surface area or lean body weight or fat-free mass, these techniques are often invasive or time-consuming which is not optimal in a resuscitation situation.[7, 8] Nonlinear weight estimation methods are often more complex and can increase cognitive loading and also the chance of error in treatment decisions and medication calculations.[61] The dilemma here is the need for simplicity and ease of calculation versus improved accuracy with increased health professional cognitive loading and longer time to treatment. Even though this dilemma is acknowledged in the literature, there is an ongoing and urgent need for more time-efficient, practical, and accurate modalities for the weight estimation of children in emergencies.

1.8.1 Accuracy of weight estimation in NZ

Weight estimation methods endorsed by the NZRC[18] and St John[36] Ambulance are shown in Table 2.

Table 2 - Age-based weight estimation endorsed by the NZRC and St John Ambulance NZ

Estimation Guideline	**< 1 year**	**1 – 9 years**	**10 – 14 years**
NZ Resuscitation Council[18] St John Ambulance NZ[36]	5 kg	2 x (age + 4) kg (APLS Formula)	age x 3.3 kg age x 3 kg

Note: age = age in years

Accuracy of age-based weight estimation is lower than in the case of length-based weight estimation techniques[27] yet NZ resuscitation protocols suggest only length-based methods if a child looks obese.[18] Furthermore, literature is not conclusive regarding what is considered an accurate weight estimate. While many studies worldwide accept a ±10%[27] of actual weight as the threshold for accuracy literature has not revealed research validating this as a cut-off point for accuracy of weight estimates during paediatric resuscitation.

Accuracy of current tools is well researched around the world; however, in NZ the scale of existing research is limited to two studies - the first in 2005 at Counties Manukau District Health Board (n = 909)[17] and a more recent one conducted in 2015 (n = 376)[16] in Auckland neither of which fully represents the NZ paediatric population. Interestingly, both studies investigated current weight estimation tools endorsed by the NZRC at the time of publication, however while both occurred in the Auckland area the 2005 study was limited to a single District Health Board (DHB)[17] whereas the 2015 study stratified across Auckland using school decile as a proxy for socioeconomic status.[16] This means that further investigation of the applicability of both of these studies to all NZ children is required.

Both studies[16, 17] concluded that weight estimation methods in NZ did not meet the needs of the population and suggested that demographics, such as gender and ethnicity influence results considerably. Worldwide, the use of these characteristics is slowly emerging, with several studies introducing weight estimation methods with the use of demographic characteristics to boost accuracy between 2009 and 2017.[14, 19, 62]

Some preliminary work to this was undertaken in my master's thesis. In this research, I investigated the accuracy of current weight estimation formulae for NZ children, which included measurement of weight, height, age, and demographic characteristics. Table 1 indicates the comparison with existing methods on a cross-section of NZ children (n = 379).[15, 16] After completion of my Master's research, I investigated the impact of ethnicity and socioeconomic factors and used this information to derive a method of weight estimation in the form of lookup tables.[14]These lookup tables improved both age and length-based weight estimation methods by including demographic factors such as age, gender, ethnicity and body habitus (Table 3) to improve currently endorsed weight estimation techniques in NZ.[14]

Table 3 - Accuracy of weight estimation using lookup tables shows improvement in both length-based and age-based weight estimation methods

	Weight estimation methods currently used in NZ[14, 16, 17]		**Novel NZ weight estimation tables including demographic information[14]**	
	Estimation Method	**±10% of measured weight**	**Estimation Method**	**± 10% of measured weight**
Age-based	APLS Formula	39.1%	Britnell age table	51.3%
	Shann Formula	45.7%		
	Theron Formula	28.7%		
Length-based	Broselow-Luten Tape	73.4%	Britnell length table	74.8%

APLS = Advanced Paediatric Life Support

To validate these findings and compare the accuracy of current weight estimation methods to a unique NZ sample, I applied for a dataset collected over five years from the NZ Health Survey which was provided by Statistics NZ for analysis in this study.[63]

Investigation of the documentation provided with this dataset showed that 99% of the NZpopulation (children and adult) were eligible to participate in the NZ Health Survey. People living in the following settings were not eligible: prisons, hospitals, hospices, dementia care units and hospital-level care in aged-care facilities.[63] The proportion of children residing in these facilities is likely to be lower than the adult population due to their nature, and therefore, it is assumed that the paediatric population eligible to be included matches or exceeds the above prediction of 99% of the NZ population.

The National Institute for Applied Statistics Research Australia (NIASRA), University of Wollongong, Australia created the sample design for this dataset[63] which has been consistent across the first four years. In 2015 to 2016 the design changed from using census mesh blocks for participant selection to using primary sampling units to decrease the overlap between government surveys and the collection of health data.[63]

The data was collected between July 2011 and June 2016, with trained interviewers from CBG Health Research Ltd conducting interviews as well as collecting demographic and anthropometric data.[64] The sample was selected using a multi-stratified probability proportional to the size sampling design, with participants selected based on geographical area with one adult and child selected from each household randomised as a participant. This design was tested using a pilot study with 100 respondents before becoming the sampling method for NZ National Health Surveys.[64]

Of particular interest in relation to this research is the demographic and anthropometry data for children, including, height, weight, age, gender, and ethnicity, which can be used for the analysis of existing methods of weight estimation and serve as a large dataset for regression modelling. The sampling framework included a sample size of 5,000 children each year, which represents a cross-section of the NZ child population.[63] A breakdown of the paediatric data that were gathered on a yearly basis is available in Table 4. Furthermore, this table indicates that interviews were conducted with 23,137 families and height and weight measurements were collected by trained staff using identical equipment, processes and techniques for 17,208 of these children.[63]

Table 4 – total dataset prior to cleaning sorted by year[63]

Date	**Total number of children included**	**Measurements available**	**Mean height (cm)**	**Mean weight (kg)**
2015-2016	4721	3636	131.8	36.0
2014-2015	4754	3590	130.8	35.7
2013-2014	4699	3587	130.0	35.0
2012-2013	4485	3230	130.7	35.2
2011-2012	4478	3165	129.7	35.2
Total	23,137	17,208	130.9	35.6

cm = centimetres, kg = kilograms

On consultation about which subset of data would be the most appropriate for use in this study, the Auckland University of Technology mathematician and statistician Dr Robin Hankin[65] suggested that aggregating the five years of data would be preferable to utilising the most recent year of data. He explained that little change over time would be evident with a dataset of this size. As anticipated, little change in the mean weight and height were evident across the five years of data (Table 4). A minimal change was apparent in mean weight (0.8 kg) with a slight increase in mean height (2.1 cm) of NZ children between July 2011 and June 2016.

For each child in the dataset variables, age (years) and weight (kg) were used to calculate ±10% of actual weight for each year of age.[63] St John Ambulance and NZRC weight estimates were calculated and the mean for each age group was plotted in Figure 2.[18, 36] Furthermore, proportions of St John (Figure 3) and NZRC (Figure 4) weight estimates are shown. Together, these statistics indicate that the NZRC and St John weight estimation methods do not match the weight of NZ children. Furthermore, if estimates within 10% of actual weight are considered accurate (as discussed above), only 21% (n = 3541) of St John and 24% (n = 4189) NZRC weight estimates would be considered accurate when applied to the dataset described above[63].

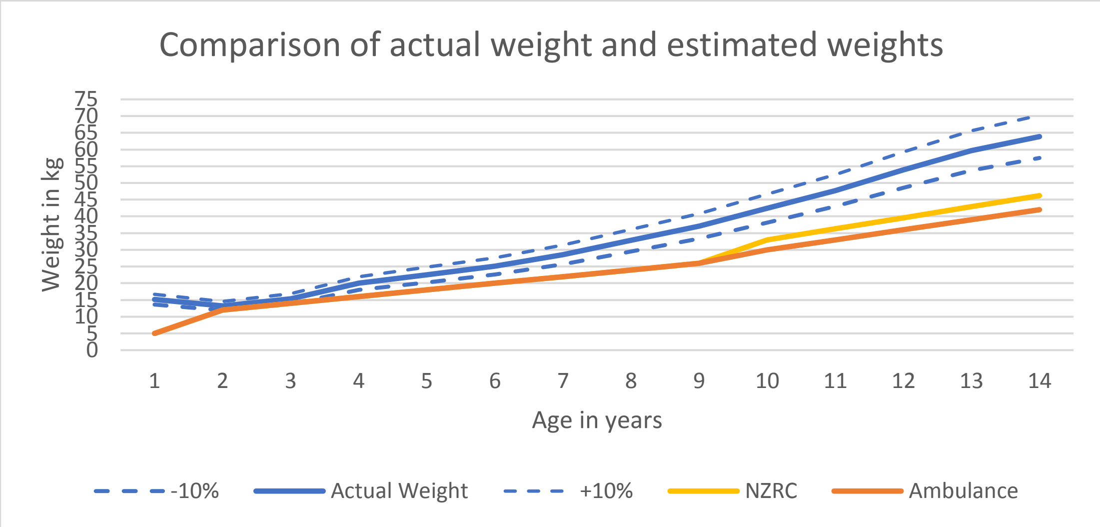


Figure 2 - NZ Health Survey data (percentiles) with current weight estimation methods plotted

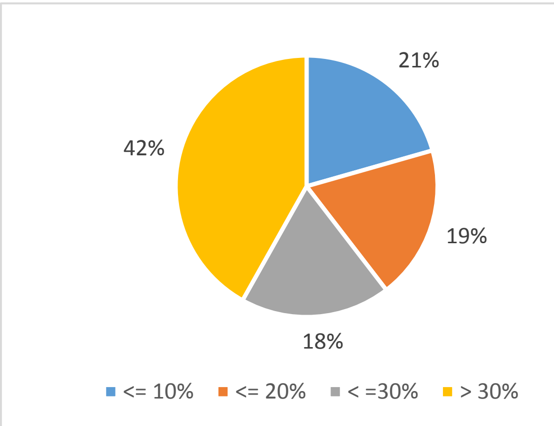


Figure 3 - The number of weight estimates within a given percent of actual weight (St John)

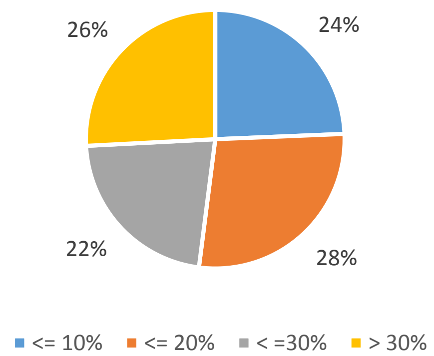


Figure 4 - The number of weight estimates within a given percent of actual weight (NZRC)

Little is known about the minimum and maximum safe doses of resuscitation medications for children. To illustrate the disparity and complexity of medication prescribing, the estimated and actual weight will be applied to the calculation of resuscitation drug doses outlined by NZRC guidelines[18, 66] for use in paediatric resuscitation (Table 6).[18] What stood out during the examination of this data was the number of medications that are either considered not safe for use in children or whose maximum or minimum safe dose for children is not stated in documentation, yet these are included in the NZRC guidelines for the resuscitation of children. Furthermore, Table 5 shows the average weight of New Zealand children. Table 6 also illustrates the variability of age (weight) as related to safe administration, which is much lower when using the current Ministry of Health data than when following the weight estimation guidelines from the NZRC and St John Ambulance procedures. [18, 36, 63]

Table 5 - Average weight of NZ children based on statistics NZ dataset[63] with NZRC[18, 66] and St John Procedures[36] for comparison

	Age in years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
	Average Weight in kg	16.9	14.7	17.1	19.4	22.5	25.1	28.6	32.8	37.1	42.4	47.8	53.9	59.7	63.9
NZRC	Weight estimate in kg	10	12	14	16	18	20	22	24	26	33	36.3	39.6	42.9	46.2
	kg difference	-6.9	-2.7	-3.1	-3.4	-4.5	-5.1	-6.6	-8.8	-11.1	-9.4	-11.5	-14.3	-16.8	-17.7
	% difference	-40.8%	-18.4%	-18.1%	-17.5%	-20.0%	-20.3%	-23.1%	-26.8%	-29.9%	-22.2%	-24.1%	-26.5%	-28.1%	-27.7%
St John	Weight estimate in kg	10	12	14	16	18	20	22	24	26	30	33	36	39	42
	kg difference	-6.9	-2.7	-3.1	-3.4	-4.5	-5.1	-6.6	-8.8	-11.1	-12.4	-14.8	-17.9	-20.7	-21.9
	% difference	-40.8%	-18.4%	-18.1%	-17.5%	-20.0%	-20.3%	-23.1%	-26.8%	-29.9%	-29.2%	-31.0%	-33.2%	-34.7%	-34.3%

Table 6 - Overview of resuscitation drugs for children[18]

Drug	**Maximum dose per kg**	**Units of measure for each drug**	**Minimum effective dose for a child**	**Maximum safe dose for a child**	**Maximum safe dose for an adult**	**Minimum effective weight for child dose**	**Maximum safe weight using paediatric dosing**	**Maximum safe dose weight for using adult dosages**	**Year the max safe dose would be reached for NZ children**	**Maximum safe dose using NZRC estimate**	**Max safe dose using St John estimate**
Adrenaline	10	mcg	100	500	500	10 kg	50 kg	60 kg	10 years	> 14 years	> 14 years
Amiodarone	5	mg	Not safe		300	Not safe		60 kg	12 years	> 14 years	> 14 years
Atropine	20	mcg	Not Stated	1000	2000	Not stated	50 kg	100 kg	10 years	> 14 years	> 14 years
Calcium	0.15	mmol	Not Stated		6.8	Not Stated		45 kg	9 years	13 years	> 14 years
Glucose (10%)	0.25	g	5-8 mg / kg / min		to maintain Blood Sugar Level						
Lidocaine	1	mg	Not stated		1 / kg	Not Stated		Unable to calculate			
Magnesium	0.2	mmol	Not Stated		5	Not Stated		25 kg	5 years	9 years	7 years
Potassium	0.07	mmol	Not Stated		5	Not Stated		71 kg	> 14 years	> 14 years	> 14 years
Procainamide	15	mg	Not Stated		Not used			Unable to calculate			
Sodium Bicarbonate	1	mmol	Not Stated		1 / kg	Not Stated		Unable to calculate			
Fluids	20	ml	Not Stated		20 / kg	Not Stated		Unable to calculate			

The application of medication data to age and weight in Table 6 has illustrated the complexity involved in paediatric resuscitation and the limited number of medications deemed safe for use in children. The concerning point is that all medications listed in Table 6 are endorsed in the NZRC guidelines[18, 66] and are commonly prescribed and administered in paediatric resuscitation.

It is evident from the data in Table 5 that calculations of drug doses are complex, and repeatedly, the research around limitations of drug doses for children is often based on adult doses without reference to research in children. Furthermore, the summary of medication information presented in Table 6 also illustrates that one solution to medication dose may not necessarily allow a one solution fits all approach.

While research on the accuracy of weight estimation is well established, the relationship between weight estimates and demographic characteristics of children is still emerging. Currently, none of the emergency weight estimation methods endorsed by the NZRC takes into account demographics, such as body habitus and ethnicity[18] even though international trends are beginning to include these.[14, 49, 52, 62, 67-69] Two NZ studies do investigate the influence of ethnicity and body habitus, on weight estimation and both suggest that including body habitus in weight estimation calculations will increase accuracy for NZ children.[14, 16, 17]

Most literature uses Body Mass Index (BMI) as an indication of body habitus, which can limit the applicability in multi-ethnic societies, where acceptable BMI differs between ethnicities.[70-72] Although the International Taskforce on Obesity (ITFO) has defined the cut-off points for BMI in children, in order to indicate obese or underweight children, these cut-off points provide a "one-size-fits-all-ethnicities" solution and do not take into account the variations in adiposity in a multi-ethnic society.[73] The two NZ weight estimation studies showcase the diverse range of ethnicities that weight estimation is required to cater for in NZ (Table 7).

Table 7 - Distribution of ethnicity in NZ weight estimation studies

Ethnicity	**Britnell[16]**		**Theron[17]**	
	n	**%**	**n**	**%**
European	151	40.2	160	18.0
Pacific	113	30.1	420	46.0
Māori	56	14.9	226	25.0
Asian / Indian	49	13.0	79	9.0
Other	7	1.9	24	3.0

Ethnicity matches the NZ census categories

Only a handful of studies investigating weight estimation in paediatric resuscitation (from Australia, NZ, the USA and the UK) have included ethnicity in their analysis; however, a comparison of these studies is difficult, due to the inconsistencies that occur when reporting ethnicity across nations. In NZ, two studies have evaluated weight estimation methods for Auckland children and have categorised ethnicity using the Level One coding stipulated in the NZ Ministry of Health Ethnicity Data Protocols.[74] Both studies recognised the impact of the body habitus on weight estimation. The first study (n = 909), which was conducted at Middlemore Hospital ED in 2005, identified that the body habitus and ethnicity influenced weight estimation.[17] The researchers found that traditional weight estimation methods were less accurate in Māori (n = 226) and Pacific children (n = 420), who were considered to be large for their age at the time of this study. The second study (n = 376) compared current weight estimation techniques for Auckland children and achieved a wider ethnic spread of participants; European (n = 151), Pacific Island (n = 113), Māori (n = 56), Asian/Indian (n = 49) and Other (n - 7).[16] Both studies found that current weight estimation methods were limited in their application due to the cultural diversity of the Auckland population and further research on the impact of ethnicity on weight estimation is required. The relationship between ethnicity and socioeconomic status was addressed in one of the NZ studies of weight estimation in children that used school decile rating as a proxy for socioeconomic status.[14] Interestingly, a significant relationship was found when correlating both ethnicity ($\tau b = 0.531$, $p = 0.025$) and school decile ($\tau b = -0.132$, $p = < 0.001$) to body habitus using the ITFO BMI cut-off points[73] for children. The second study mentioned above used this data to produce new weight estimation tables tailored to Auckland children. Table 3 in section 1.8.1 shows that the lookup tables outperformed the Broselow-Luten tape (a length-based) weight estimates by including height, ethnicity and body habitus, while for age-based methods, the inclusion of data on ethnicity, body habitus, and gender produced estimates that were considerably more accurate than existing NZ age based weight estimation methods.[14] To date, no other Australasian studies of weight estimation have included ethnicity, body habitus and gender to improve the accuracy of weight estimation during paediatric resuscitation; therefore, further research is required to validate these findings in Australasia.

While a streamlined process of weight estimation specifically tailored to NZ children may decrease ad-hoc estimation methods such as the one described earlier, I believe that using mobile technology could further assist in optimising these repetitive tasks and calculations. This could lead to a decrease in errors and the bias introduced by human factors.

1.9 Research Aim

Design, build and test an application that will return an accurate weight (and therefore body surface area) estimate for NZ children in multiple environments. The user interface will be straightforward with weight estimates tailored to NZ children, by using NZ-specific data and demographic characteristics of children to increase the accuracy of weight estimates.

1.10 Thesis Structure

On examination of existing design science theses, the structure differs between authors and from a traditional thesis structure. A pivotal work by Jones and Gregor[75] examined the literature around the presentation of design science research to ensure that a structure was provided for artefacts that were material (e.g., software) or abstract (e.g., theories) in nature. They suggested the following sections: Purpose and scope, Constructs, Principles of form and function, Artefact mutability, Testable propositions, Justificatory knowledge, Principles of implementation, and an Expository instantiation. However, the categories suggested above do not entirely fit with a thesis structure. Therefore, this thesis will adapt the traditional structure slightly to meet the needs of software development. Chapters headings are listed below:

- Chapter One - Introduction
- Chapter Two – Literature Review (completed in 2017)
- Chapter Three – Literature Review Addition (added in 2019)
- Chapter Four - Methodology
- Chapter Five – Prototyping and Experiments
- Chapter Six – Application design and initial development
- Chapter Seven - Testing
- Chapter Eight – Discussion and Implications for Practice

A more detailed description of how the content of these chapters is linked to the design science research (DSR) process and results of this research will be presented at the end of Chapter Four on the Methodology. Furthermore, as prototyping, design, development and testing also often include a series of self-contained experiments, the structure of DSR will be covered in Chapter Four. In contrast, methods for self-contained experiments in chapters five, six and seven are included in these chapters.

The citation style and reference list will be in IEEE format that is commonly used in computing literature and recommended by supervisors of this research. While an IEEE style guide is available for journal authors,[76] this does not meet the formatting standards required for this thesis[77] or long documents, therefore an adapted APA[78] style will be used for tables and captions with numbered headings that are typical in many computing and mathematics theses.

1.11 Conclusion

In paediatric resuscitation every second counts. Providing lifesaving treatment for children requires knowing the weight of the child to calculate medication doses and equipment needed. Measuring weight when a child cannot be moved necessitates weight estimation. However, this chapter has established that current methods of weight estimation have a low to moderate accuracy and are designed for non-NZ children and as a result, clinicians appear to be adapting weight estimation in an ad-hoc manner during resuscitation. An incorrect weight estimate can impact on a child's survival, and the variability of the resuscitation environment and changing demographics of children in NZ can influence the accuracy of weight estimation.

To improve the accuracy and consistency of weight estimation in paediatric resuscitation, this research will outline the development of a mobile application called Weight Estimation without Waiting (WEWW). The main aim of WEWW is to reduce the chance of error and time to treatment by automating weight estimation by using mobile technology and image analysis tailored to NZ children. This thesis will concentrate on the design process and prototyping of the WEWW application and will include user testing and some preliminary work around the accuracy of the application.

2 Chapter Two – Literature Review

2.1 Introduction

During resuscitation, every second counts. Providing lifesaving treatment is often time-critical and complex with treatment decisions made in high stress and chaotic environments.[8, 79] Insufficient time and patient information are common and when coupled with the possibility of unanticipated events, produce a high cognitive load and increased the potential for error.[8, 59, 79]

While both adult and paediatric resuscitation share all this potential for error, paediatric resuscitation is further complicated by the need to adjust medications and equipment size based on the weight of the child.[8, 80, 81] Therefore this scoping literature review investigates the use of mobile technology use in resuscitation with a view to locating mobile technology related to weight estimation.

2.2 Background

Resuscitation of children often occurs in the pre-hospital and Emergency Department (ED) settings. The proportion of presentations which require resuscitation is challenging to determine due to varying definitions. For example, resuscitation often refers only to cardiopulmonary resuscitation (CPR); however, as this scoping review reveals, resuscitation can also include medical conditions such as stroke or trauma.[82, 83]

New Zealand (NZ) ED statistics reveal that 154,396 children under the age of 15 attended an ED between mid-2014 and mid-2015.[55] While the exact number of children requiring resuscitation is unknown, a study of NZ and Australian EDs categorised 27% of children as Australasian Triage Category 1 or 2,[3] i.e., a life-threatening illness or injury requiring treatment immediately or within 10 minutes of arrival.[56] This means, potentially, that 41,686 children presenting to an ED may require resuscitation. Furthermore, these statistics only include presentations to District Health Board (DHB) EDs and exclude pre-hospital and primary care presentations not linked with a DHB. Therefore, this figure may underrepresent the prevalence of paediatric resuscitation and the need for weight estimation.

Providing prompt quality CPR in emergencies is time-critical to the survival of the victim.[84] With the emergence of personal mobile devices like smartphones and smartwatches, studies are beginning to suggest that mobile devices can alter the quality of CPR, which, in turn, may also alter chances of survival after CPR. Therefore, this scoping literature review will primarily explore literature related to mobile technology in resuscitation, with a secondary aim of locating any research around the use of mobile technology in weight estimation for paediatric resuscitation.

2.3 Definitions

Mobile technology is defined as portable technology and often includes devices, including mobile phones or tablets. Using mobile technology in health is called mHealth (a component of eHealth), which the World Health Organisation (WHO)[84] defines as medical and public health practice supported by mobile devices like mobile phones, patient monitoring devices, and personal digital assistants. Throughout this review, mobile technology will refer to portable devices, primarily smartphones and tablet technology.

2.4 Methods

This scoping literature review follows the Joanna Briggs Institute (JBI)[85] scoping review protocol, with one exception. JBI suggests a second reviewer of data would minimise reporting bias; however, this thesis is the work of a sole author (PhD candidate), which is a limitation of this review. A JBI scoping review was selected as this provides a protocol for a broad field (use of technology in resuscitation) rather than to answer a narrow specific question often used in systematic reviews such as Cochrane Reviews. Furthermore, Johanna Briggs is a protocol for scoping reviews is used commonly in Australasia where this study was conducted.[85]

Inclusion criteria were studies that were directly related to resuscitation of a person which included the use of mobile technology. The Auckland University of Technology library service is managed using the EBSCO Discovery Service, which consists of all subject areas and searches multiple databases, including Google Scholar. This service supports printed and electronic material, both internal and external to the University and allows the request of content from other institutions.

A keyword search using the terms: *resuscitation AND (mobile technology)* revealed a total of 142 manuscripts across the following databases: EBSCO Discovery Service keyword search (87), Web of Science MESH topic search (46), Cochrane Systematic Reviews keyword search (1) and MEDLINE keyword search (8). The exclusion criteria were, non-English (5) and non-full-text (12), editorials and letters (5) as well as unrelated books (1) and 60 duplicate papers were removed. This left 66 papers for screening.

The title of each manuscript was analysed for common words using textalyser.[86] This revealed the ten most frequent words, in order: resuscitation, mobile, cardiopulmonary, cardiac, arrest, technology, emergency, CPR, extracorporeal and during. These terms were used to form a new search string, ((resuscitation OR (cardiopulmonary resuscitation) OR (cardiac arrest)) AND (mobile technology), and a search was carried out with the same parameters as the search above. Results revealed EBSCO Discovery Service (120), Web of Science (46), Cochrane Systematic Reviews keyword search (1) and MEDLINE keyword search (8). After the removal of duplicates and those included in the first search, 56 new studies were added for screening.

Combining both searches gave 122 studies. Through a manual screening, further items were excluded: letters to the editor (1), no full-text (7), non-English (2) and non-research (1) manuscripts were removed. Furthermore, manuscripts not related to resuscitation (46) or mobile technology (29) were screened out, leaving 36 manuscripts. Reference lists of selected manuscripts were examined for any further literature that met selection criteria and four manuscripts were added.

2.5 Discussion

The literature was separated into two categories to allow easy differentiation of where mobile use technology occurred. These were labelled, before resuscitation (before hands-on treatment) or during resuscitation (during hands-on treatment). Each category contained subcategories to allow easy identification of studies of mobile technology used during treatment (Table 8). These will form the major themes within the discussion of the scoping review that follows.

Table 8 - Categorisation for selected manuscripts

Before Resuscitation	**15**
Training	7
Dispatch	8
During Resuscitation	**39**
Reference or guidelines	4
Checklists or decision support	7
Real time feedback	22
Video conferencing	3
Hardware and Sensors	2
Documentation	1

2.5.1 Before resuscitation

Training

Mobile applications that provide training support for bystander CPR are emerging. However, their quality and adherence to resuscitation guidelines are variable. A 2012 study identified 46 apps for Android or Apple devices containing Basic Life Support (BLS) or Advanced Life Support (ALS) material.[87] Experts and laypersons examined the purpose, usability, quality and adherence to guidelines finding that few applications adhered to resuscitation guidelines or were easily usable for laypersons.[87] This study is on adult CPR, and the addition of paediatric data could prove beneficial. While healthcare applications are not regulated in NZ, the Ministry of Health does provide suggestions for healthcare professionals in evaluating healthcare applications for patients.[88]

Bystander CPR

A Croatian cohort study used a tablet to simulate an Automated External Defibrillator (AED) (n = 124) during a basic life support course.[89] CPR and AED knowledge increased after the course along with participants attitude towards using a simulated AED versus a traditional AED trainer. Use of the simulated AED was rated using a Likert scale with 1 (strongly disagree) to 5 (strongly agree): students reported the AED simulator did not diminish their education experience (4.5/5), was a useful tool for practice (4.7/5), there were no difficulties when switching from training AED to simulated AED (4.5/5) and they did not notice significant differences in operation (4.3/5).[89] The focus of this study was adult CPR and AED use, therefore, future developments, including paediatric defibrillation simulation on mobile devices where the weight of a child is utilised to calculate kilojoules for defibrillation could be beneficial.

Two studies compared traditional with mobile modalities for teaching resuscitation skills to the public. A cluster randomised trial measured the retention of CPR knowledge in 1232 Swedish children (13 years)[90] using traditional DVD instruction (50 minutes) versus smartphone based training (30 minutes). Traditional DVD education continually outperformed SP learning at baseline (36 versus 33 points, $p = <0.001$) and at 6 months (30 versus 28 points, $p = <0.001$). Results may have been biased by the duration of the training and the age of participants in comparison with the general population. Therefore, further investigation into training modalities, attitudes and uptake in a cross-section of society is warranted.

Retention of knowledge was the focus of a 2016 study by Elliot-Slither and Fatimah,[91] who aimed to validate smartphone software that used an accelerometer to measure CPR compression depth and rate. The authors report that using smartphones to guide CPR can assist in increasing the depth of chest compression. However, a limitation is that differing accelerometer models across mobile devices could impact the accuracy of these results. A significant amount of data was presented; however, it was difficult to determine which measures were used to validate the software, and minimal synthesis of information was apparent. More than three-quarters of the adult participants (79%) dropped out before the 6-month follow-up, leaving a small sample ($n = 67$) for analysis. This reduction in power and sample size, no evidence of ethics approval, and difficulty determining the measures used in the study bring its validity into question.

Furthermore, the last statement in this study appears to advertise the software for public consumption. Comparison of this study with others was difficult as measures were complex and not explicitly linked to the outcomes. With differing depths of compression recommended by the NZRC for different sized children,[92] investigation of this technology in paediatric CPR compressions would be valuable.

Gamification of resuscitation training is emerging; a three-cycle-design science pilot study outlining the development of a game, *HeartRun*, to educate first responders about decision-making in an emergency[93, 94] included user testing with a cohort of schoolchildren aged 12 to 18 to guide development. Findings revealed that game-based environments could be integrated with physical tasks like learning CPR or using an AED, while encouraging collaboration.[93]

Gamification of training can both motivate and demotivate students. Applegate, Aitkin, Chang and MacKinnon also used gamification to engage teenagers (16–18 years) in learning CPR with an AED.[95] They introduced competition by exporting test data to an online leader board. A pre and post questionnaire (n = 193) revealed gamification had positive (21.8%) and negative (14.1%) connotations. Some students who felt negatively about gamification said the leader board trivialised CPR (3.83%) or made them feel self-conscious (14.1%).[95] Students who were positive about gamification liked technology (8.67%) and reported that gamification made it more enjoyable (6.65%). Furthermore, for some students (19.4%), learning was improved by including a tangible "reward" for high scores.[95]

The impact that game-based learning has on CPR knowledge is equivocal. Latif, Ajmal, Ahmad, Alam and Saleem[96] launched a game called *LA-VIE* in 2017 to assist health professionals to learn the guidelines and process of CPR. A pre and post-test to evaluate the learning of 52 students (with no prior CPR training) found a general increase in CPR knowledge from playing this computer game. However, evaluation of this study is difficult as formal methods are not reported. Interestingly, a similar study that compared a mobile location-based collaborative role-playing game to traditional CPR in children aged 12 – 18 years found that providing mobile training had no significant impact on CPR knowledge (chi-square test = 1.94, $p > 0.380$).[93]

Many of the gamification studies have used children to test CPR games, even though their aim was healthcare professionals. Further investigation is required to evaluate the application of gamification to healthcare professionals.[93, 95, 96] Furthermore, all studies around gamification presented above were designed around adult CPR, and similar studies need to be replicated to provide valuable insight into the gamification of paediatric resuscitation.

Healthcare professional training and education

The prevalence of training material available on mobile devices allows convenient access to information and is an effective method of increasing learners knowledge around resuscitation.[97-99] One study of doctors (8 junior and 12 senior) employed in a neonatal intensive care unit in the United Kingdom (UK) investigated using a simulated neonatal resuscitation application designed to increase knowledge and skill related to neonatal resuscitation.[87] The application included videos and a calculator for equipment sizes. Pre-testing and post-testing showed a significant increase in knowledge related to indications, complications, equipment required and calculations, after using the application (mean: pre 18.5/45, post 31/45, $p = 0.001$).[87] Even though a minimal increase in performance of practical skills was apparent (mean: pre 11/17, post 12.5/17, $p = 0.044$) a reduction of 8 seconds in the time taken to intubate was achieved. The authors of the study acknowledged the choice of pre-testing and post-testing without a control group could have biased results in their study.

A similar increase in knowledge was observed in a Korean study of 93 nursing students who participated in a randomised controlled trial of smartphone-based learning around paediatric airway obstruction using pre-testing and post-testing.[100] Knowledge improved to the same level for both control (mean: pre 9.7, post 11.8) and experimental (mean: pre 8.7, post 11.8) groups after smartphone or traditional education. The main difference in findings between this and the previous study was an increase in skill performance between the control (mean: post 6.7) and experimental (mean: post 12.0) groups. The increase in skill acquisition/performance in the second study may relate to the training, clinical experience and role of participants. For example, doctors in the first study were already working in a neonatal intensive care unit, which may account for the minimal change in skill post-smartphone and video learning, whereas the nursing students in the second study had no previous experience or expertise in infant emergency care. This also meant that they had no prior experience to influence their opinion of training using a smartphone. Therefore, further investigation of the impact of previous training and knowledge on skill acquisition with mobile learning needs further analysis.

Dispatch

Because early CPR is known to save lives, prompt emergency calls, dispatch and response can also directly impact survival from resuscitation.[101] Making emergency calls to the ambulance dispatcher via smartphone (as opposed to landline telephones) is shown to increase the quality of dispatcher-assisted CPR due to features like portability and speakerphone function allowing continuous feedback and advice while providing care.[102] Newer capabilities, including a Global Positioning System (GPS) can also streamline out-of-hospital cardiac arrest (OHCA).

A study set in the USA[103] reported the production of a smartphone application using current mapping and GPS on mobile phones to locate AEDs on college campuses. While this study introduced the concept of using mobile technology to locate an AED, scientific evidence to validate the application was not reported. Future research that validates this tool would be beneficial. An advantage of this study was that it defined the finite geographical boundaries of college campuses and a known maintenance schedule of AED was included.[103] However, such scalability may be problematic in larger areas where AEDs are not maintained by one organisation. One study introduced crowdsourcing as a means to alleviate this problem, asking workers to locate and verify 40 AEDs around Philadelphia as proof of concept.[104] While a potential solution for scalability, validation of this concept against varying protocols and policies is required to maintain AED location and maintenance information. Furthermore, AEDs are generally utilised on children over the age of 7 years, so a similar mapping process would have to provide information on facilities equipped with paediatric resuscitation equipment or defibrillation capabilities.[105]

One solution suggested was the development of a semi-automated robot activated via a smartphone application to deliver an AED to a cardiac arrest victim.[95] While this initiative reduced time to treatment by removing the need to fetch an AED which could increase chances of survival[101], it did not guarantee the confidence and competence of the bystander utilising the AED. Therefore, further validation of robot-delivered AED is required. A similar concept which removed some of the time needed to locate the AED by using a GPS enabled smartphone application to dispatch the nearest qualified person with an AED to the location of a cardiac arrest, may assist in the reduction of time to treatment.

GPS can increase dispatch speed of trained and lay personnel or equipment in an attempt to improve time to treatment and ultimately initial survival rates.[106-109] However, statistics on the influence of smartphone application dispatch on those patients who survive to discharge from the hospital do not improve[107] this disparity warrants future investigation of the role of technology in initial survival compared with discharge survival rates.

A comparison of the traditional Short Message Service (SMS) versus smartphone application to dispatch bystanders to an OHCA[107] led to a 2.1 minute ($p = 0.001$) decrease in dispatch time when using a smartphone application. However, data were collected over a four-year period where the technology may have moved forward during data collection. A shorter study[108] indicated a similar reduction in bystander response time using a smartphone application, 2 minutes and 20 seconds (44%, $p<0.001$, 95% CI, 1min 5s – 3min 35s) when compared with ambulance response times where bystanders were not dispatched. A limitation of this study was that the setting was a controlled, simulated environment that did not anticipate features of real-life situations,[108] for example, the difference in the proximity of the bystander and ambulance as well as need to locate and collect an AED. Furthermore, as discussed above, if the patient is a child, specialised equipment, including smaller AED pads, may be required. Future research on dispatch of bystanders with AEDs needs to consider paediatric requirements.

The initiation (first hands-on compressions in CPR) of bystander CPR in OHCA increased with the use of a smartphone application. One randomised controlled trial investigated the dispatch of bystanders located within 500 metres of an OHCA ($n = 667$).[110] An increase in the initiation of CPR (48% to 62%, $P < 0.001$) was apparent when dispatched using a GPS mobile phone application.[110] However, this study did not measure the survival rate in comparison with other forms of initiation of CPR. Limitations of this study included the exclusion of GPS data at night and for specific types of environment (including drowning). Also, the restriction on activation of responders to a 500 m radius makes the evaluation of this study difficult. The paediatric population was not included in this study; the inclusion of data related to a cardiac or respiratory arrest in children would be beneficial.

Public opinion of a crowdsourced alert system to dispatch CPR trained staff to cardiac arrest was investigated using existing online survey platforms in the United States of America (USA) and Canada over one week in 2015.[111] 2415 members of the public responded; of this, 79% indicated they would like this system to be implemented in their community. However, only 62% were likely to download the application. Interestingly, 90% of the participants felt it was essential to give responders accurate GPS information. However, the public was less comfortable with responders attending cardiac arrests in private settings (70%) versus (78%) in public settings. While survey questions studied public response to CPR, no differentiation was made between paediatric or adult resuscitation.

It is worth noting that while the literature reports rapid development of mobile applications to dispatch bystanders, many authors focus on software design, which often makes the comparison between studies difficult and shows a need for further validation.[103, 112]

Providing a guide or direction can improve some aspects of bystander CPR; however, mobile technology needs to improve rather than distract from the delivery of CPR. Several studies have compared smartphone training or guidance versus traditional instruction for CPR in a simulated environment, and all reported an improvement in bystander/layperson CPR when using a smartphone application as a guide.[113-116] Comparison of some studies is difficult due to differing measures, and as an example, a 2007 study[113] analysed the inclusion or exclusion of critical points in resuscitation with one group using a smartphone application versus a control group with no application. Other studies (Table 9)[115-117], reported an improvement between experiment and control groups across all measures. One common measure was the hands-off time, which decreased when using smartphone guidance; however, the level of improvement varied.[115-117] This variance could indicate differing aims and measures between studies; however, as further research emerges using common measures, a more detailed comparison may be possible.

Table 9 - Comparison of studies using smartphone guides to enhance bystander CPR

	(Sakai et al. 2015)[117]		**(Hawkes et al. 2015)[115]**		**(Merchant et al. 2010)[116]**	
	Smartphone (n = 43)	Control (n = 46)	Smartphone (n = 10)	Control (n = 11)	Smartphone (n = 80)	Control (n = 80)
Call for Help (%)	67.4**	46.3**	80**	36.4**		
Correct Compressions (%)	100*	75.6*	90**	45.5**	97.0 ~	75.0 ~
Hands Off Time (s)	4.4 ± 11.7*	63.8 ± 23.1*	70.0**	81.8**	74.0 ~	89.0 ~

* p ≤ 0.001, ** p ≤0.05, ~ 95% CI

All studies in this search that presented references and guidelines as above were related to adult resuscitation. Further research on the relationship between mobile devices and the quality of

CPR or time to treatment in children could provide valuable insight into the use of technology during paediatric resuscitation.

Checklists and reference materials are a popular way to ensure safety and are used widely in many professions including surgery and the aeronautical industry.[7, 118-120] Moreover, this search strategy returned seven full-text results relating to checklist use. Checklists are increasingly being migrated to mobile devices; one example of this in paediatric resuscitation is the *PediCrisis* application, endorsed by the Society for Paediatric Anaesthesia in the United States of America (USA).[120] This study analysed the use of the application and presented some interesting insights around usage statistics. Although this application was released in the USA, users in non-English speaking countries had the longest session times and duration browsing each screen. Furthermore, returning users spent more time using the application than new users, with the most visited treatment algorithm relating to anaphylaxis.[120]

Alongside reference applications, decision support systems are emerging for mobile devices. For example, a randomised controlled trial tested paper-based versus smartphone decision support for trauma unit bypass by ambulance staff in the UK. Findings showed similar mean positive predictive value (PPV) for both paper, 0.76 (0.44 to 1.00), and the mobile-based system, 0.86 (0.80 to 0.92), which means both paper-based and mobile systems operated comparably.[121] Interestingly, the PPV range was wider in the paper-based system; that may be related to the mobile device's automatically ignoring data within the normal range whereas this was not the case in the mobile-based system.

A randomised controlled trial investigated a voice-activated decision support system, including video instruction to assist bystanders in performing CPRin a simulation.[122] Participants were 31 volunteers who had limited, distant (timeframe not specified) or clinical training in CPR; these were split into a test (n = 16) and a control group (n = 15). The authors found participants in the test group who used voice-activated decision support were more likely, 15/16 (94%), to provide the correct compression-to-ventilation ratio than the control group, 4/15 (27%), who did not utilise voice-activated decision support . They also found the test group switched roles in compressions regularly 12/16 (75%) whereas the control group did not 2/15 (13%). One statistically significant finding was that using voice-activated decision support increased the time to treatment 159.5 (±53) versus the control 78.2 (±20), which shows a need for further validation and research around voice-activated decision support systems. While this particular decision support system catered only for adults, the literature suggests that paediatric cardiac arrest is less common and more decision-dense than adult resuscitation.[8, 81, 123] Decision density refers to the amount and complexity of decisions required of the clinician performing CPR and is generally higher in paediatric resuscitation due to the complexity of prescribing and equipment selection based on weight or body surface area. Even though voice-activated decision support or video could act as a prompt for clinicians to recall rarely used protocols (such as CPR) these systems could also distract clinicians resulting in increased cognitive load, errors and alter the chances of patient survival. With this in mind voice activation and video support may benefit or could hinder paediatric resuscitation and further research around the applicability of these solutions to children is required.

2.5.2 During resuscitation

Reference or Guidelines

The use of mobile technology to reduce time to treatment is currently emerging. Studies of the use of mobile technology in the pre-hospital setting have often measured door to needle times (arrival to medication), coupled with structured protocols and apps with reminders, time tracking and notifications. These interventions have been shown to improve patient survival after a stroke.[82, 124] While both of these studies reported a reduction in time to treatment of stroke patients, the comparison between them is difficult because outcome measures did not match. For example, a prospective 2017 study[124] showed an average reduction of 21 minutes in the door to needle time when compared with current timeframes. On the other hand, a retrospective[82] study reported the reduction in comparison with a goal timeframe of fewer than 60 minutes. Although these studies utilised different measures, both reported a decrease in the door to needle/medication time.[82, 124]

Medication and prescribing

As discussed above, reduction in time to treatment can directly impact patient outcomes, and similarly, using mobile technology can decrease the incidence of medication errors. In an attempt to reduce errors in the paediatric setting, one study used patient-centred mobile technology whereby parents documented the health history and information about their child electronically to decrease preventable medication errors for children.[125] However, findings revealed that the use of this technology had little impact on the rate of medication error.[125] With this in mind, perhaps studies investigating the direct use of mobile technology by the healthcare professionals themselves could decrease errors in prescription and administration of medications for children.

Prescribing for children requires consideration of pharmacokinetics and pharmacodynamics and includes calculation of medication doses which can be based on ideal body weight, actual body weight or body surface area.[126] These considerations add a layer of complexity to resuscitation and are an area where mobile technology can assist.

Many infusions, including inotropes, insulin and fluids in burns resuscitation are considered challenging to prescribe and administer for children, as complex calculations are required to ensure safe delivery. A 2011 study investigated using a smartphone application to assist with prescribing inotropes, where doctors (n = 28) and medical students (n = 7) performed two calculations. One calculation used the paper-based the British National Formulary for Children (BNFC) guidelines, and the other used the smartphone application designed to calculate inotrope infusions.[127] A significant reduction in prescribing error was evident when using the smartphone application where 100% of calculations were correct versus BNFC, where 28.2% were correct. Similarly, errors in prescription and calculation of fluid resuscitation in burns reduced when using apps on smart devices to calculate fluid resuscitation. The percent of error with the traditional use of a calculator was 16.7% ($p = 0.065$) as opposed to smartphone apps *MerseyBurn* and *uBurn,* which both showed 7.8% error ($p = 0.065$), however, it is worth noting the p-value for both of these studies is 0.05.[128] A reduction in medication errors was noted amongst 20 paediatric emergency nurses' administration of resuscitation medication doses: traditionally calculated doses showed 70.0% error and use of the *PedAMINS* application reduced this to 0.0% (CI 95% 41.4-97.5) error during simulated cardiac arrest.[81] Furthermore, a recent study that used tablet software to assist prescribing and administration of medications also claimed a reduction in medication errors.[129] However, this was only a brief report lacking detail or statistics, which meant a thorough review was impossible.

Mobile technology has led to a reduction of time to treatment in both the prescribing and administration of drugs during paediatric resuscitation. A comparison of the paper-based BNCF guidelines with a smartphone application for calculating medications led to a mean time saving of 317 seconds ($p < 0.001$, 95% CI 267–364.5) when using the smartphone application.[127] Participants also reported increased confidence in prescribing when using the smartphone application over BNFC. A more recent study evaluated the time it took 20 emergency nurses to prepare and begin delivery of an infusion using the mobile phone application *PedAMINES* to calculate infusion requirements based on the age and weight of a child, in comparison with traditional tables.[81] Time to delivery of continuous infusions significantly decreased using *PedAMINS* (dopamine by 180.0 seconds, noradrenaline by 54.7 seconds). The reporting of this study was via descriptive statistics, and no p values were included; this may have been influenced by the small sample size, which may have impacted statistical analysis.

One area where mobile devices may assist in the reduction ofmedication errors and time to treatment is in weight estimation during paediatric resuscitation. While a plethora of research exists testing the validity of current methods of weight estimation for paediatric resuscitation (with novel solutions presented frequently), a gap is evident in literature discussing mobile technology to estimate the weight of children in resuscitation. While several studies have used mobile technology to calculate equipment size and or infusion rates, no study to date has reported using the smartphone to measure children for weight estimation, which shows a need for future research.[81, 115]

Real-time feedback

A mismatch in demographic characteristics of those requiring CPR and those who would use a smart device could influence the uptake of mobile technology during CPR. For example, a recent study in Ishikawa, Japan, compared dispatcher-assisted (DA) CPR via landline and mobile phone (n = 2530).[102] Uptake of DA-CPR was higher in mobile phone users 353/438 (80.6%) versus landline 1130/1594 (70.9%). While the initiation of bystander CPR has increased the chance of survival at one month in those patients where mobile phone dispatcher-assisted CPR (9.1% versus 7.8%), little difference was observed for those who used a landline (4.3% versus 4.6%). Survival rates at one year were consistently better for mobile phone (3.5% versus 1.9%) regardless of the initiation of CPR.[102] A limitation recognised in this study was that the mobile phone carriers were in younger age groups and therefore more likely to be familiar with mobile phones. In contrast those requiring CPR were generally in older age groups which are often less familiar with the technology. This is mirrored in NZ where a similar pattern of smartphone uptake was apparent, where the majority of smartphone owners are under the age of 55 years (91% = 18 to 34 years, 78% = 34 to 54 years, 45% = 55+ years, n = 1075).[130] yet the age of those requiring CPR in NZ is in the older age group (mean age, male = 66 years, female = 70 years).[131] Due to this mismatch in demographics around smartphone use, the impact of age and the availability of technology to those providing and requiring resuscitation needs further investigation.

Smart devices can successfully give feedback on the quality of CPR. However, limitations such as vibration and screen alerts could also distract the user from resuscitation. While multiple studies have shown an improvement in depth and/or rate of compressions when using smart devices for direct feedback, due to a different grip, position, technique of compressions, methods of data analysis and reporting, comparison across studies was difficult.[102, 132-134]

Two studies, one from Hong Kong[132] (n = 50) and other the UK[97] (n = 118) compared the *PocketCPR* application during simulated CPR using a smartphone gripped in both hands to measure depth and rate of compressions. Although these studies used different measures (Hong Kong using cm versus the UK using % accurate), compression depth was shown to be more accurate (deeper) in both studies when using *PocketCPR*. In the Hong Kong study, Scenario One revealed compression depths of 5.22 cm versus 4.56 cm (p=0.002) and 5.30 cm versus 4.56 cm (p=0.001). Scenario Two yielded 5.34 cm versus 4.56 cm (p<0.001) and 5.35 cm versus 4.49 cm (p<0.001). The UK study showed the compression depth was accurate 90.86% of the time versus 66.26% (p = <0.001). Although, the compression rate was slower (less accurate) in the Hong Kong study during both scenarios (105.19; 118.58, p<0.001; 105.23; 119.36, P<0.001) and (106.10; 121.08, p<0.001, 106.61; 117.42, p=0.002), the UK study was reported differently. Although the percent difference was minimal, it is considered significant (44.28% versus

40.57%, $p < 0.001$).[97, 132] Further investigations with comparable reporting styles are required to evaluate the *PocketCPR* application further. Both of the above studies investigated adult CPR. The different compression rates and depths required in paediatric resuscitation were not evident in the literature. Therefore, further investigation of the application of direct feedback via mobile devices is required in paediatric resuscitation.

The environment impacts CPR performance and therefore, any direct feedback provided by a mobile device. Performing CPR on a soft mattress could decrease the efficiency of CPR as the mattress absorbs compression meant for the chest of the patient. In my own clinical experience, a firm mattress or a board slid under the patient stop compression of the mattress and allowed more effective CPR. This is relevant in the measurement of compression using a smartphone as a differentiation between compression of the patient chest and mattress could falsely report an accurate compression depth. Interestingly, compression depth measurement has also been found inaccurate on soft hospital beds.[135] Therefore, a recent study tested direct smartphone feedback using three different target depths, with clinicians performing CPR on soft hospital beds. The mean chest compression depth targets were 5, 6, and 7 cm, and the following results were achieved: 45.42 (±5.79), 52.69 (±4.18), and 58.47 (±2.48) mm, respectively ($P < 0.001$).[135] However, information on the acceptable margins of error in chest compression is limited and further research around acceptable error in the depth of compressions would allow a more robust study and improvement of the accuracy of smartphone measurement of compressions.

In 2016, Amemiya and Maeda[102] tested their CPR feedback algorithm on an Android platform with an HTC Nexus One smartphone gripped in the hands (RMSE 2.94 mm, $p = 0.89$) and in a sports armband (RMSE 7.46, $p = 0.28$). They encountered a limitation where participants accidentally pushed buttons when the smartphone was gripped during chest compressions. However, an alternative exists with the emergence of smartwatches that provide biofeedback during CPR. One study which compared smartwatch feedback versus no feedback during CPR found no difference in chest compression rate and minimal difference (0.2 mm) in chest compression depth, among medical students with no real-life CPR experience.[134] The authors contended users might have difficulty feeling the vibration alerts of a smartwatch, which provide feedback about the quality of chest compressions, resulting in the need to look at the alerts. However, they did not acknowledge the potential risk of distraction by technology in recognition of the impact this would have of hands-off time or incorrect hand-positions associated with viewing the smartphone or smartwatch screen for feedback during compressions.[134] Furthermore, the above studies concentrated on adult CPR; inclusion of paediatric participants would allow investigation of direct feedback in comparison with the varying size of paediatric patients and therefore warrants further investigation.

The position of the device during CPR can also impact the accuracy of results. A recent study found that smartwatches (strapped to wrist) and smartphones (strapped to upper arm) both provided accurate feedback on the quality of compressions during CPR when compared with results from a calibrated Resusci Anne CPR training mannequin supplied by Laerdal.[133] While the authors of this study found a minimal error in depth of chest compressions in comparison of smartphone and smartwatch, (smartphone 4.6 mm; 95% CI 4.1 to 5.3 mm; smartwatch 4.3 mm; 95% CI 3.8 to 5.0 mm), other studies have shown more variable results. For example, an earlier study also found smartwatches (strapped to wrist) to be more accurate than smartphones (held in hands) when measuring the depth of compressions (smartphone 3.4 mm vs smartwatch 2.1 mm; $p = 0.008$). Interestingly, the errors increased with the depth of compressions (55 mm: smartphone 5.3 mm vs smartwatch 2.3 mm; $p = 0.023$).[136] However, the position of the smartphone was different in both of the above studies which may have impacted accuracy. Therefore, further investigation around the impact of the position of the mobile biofeedback device during CPR feedback is required. Also, differing compression depths in paediatric resuscitation, coupled with device position, require exploration.

Video conferencing

Video conferencing via mobile phone is emerging for layperson resuscitation using DA- CPR, and studies suggest a balance between the potential increase in quality of resuscitation and video quality is necessary. Although multiple studies report an increase in the quality of chest compressions using video conferencing during CPR, differences in reporting and environmental variables make a direct comparison of these studies difficult.[101, 137-139]

One study tested video conferencing during simulated resuscitations, where high school students ($n = 180$) performed CPR via audio or video calls guided by an experienced hospital dispatch nurse. While many variables like ventilation volume, depth of compressions and hand position were measured in this study, only two were significant. Video instruction decreased the hands-off time by 28 seconds over 10 minutes ($p = 0.05$), time to compressions and time to ventilation by 29 seconds over 10 minutes ($p = 0.16$) when compared with audio instructions.[140] Although this reduction in time could increase survival. The authors claimed that using video instead of audio led to minimal improvement in the quality of CPR. They did, however, acknowledge the impact of inadequate staff training and limited data bandwidth on their study and suggest that further research is required to determine how best to overcome these limitations.[140]

A subsequent study reported a decrease in video quality during night-time CPR scenarios with video conferencing between bystander and emergency dispatcher.[141] This study used a mobile phone (iPhone 5) during simulated resuscitations in various settings, with a focus on video quality and other measurements of quality including the number of repetitions of instructions and successful completion of tasks. The quality of video in low light was a limitation with dispatchers unable to see whether instructions were carried out in 3/90 (3.0%, P=0.0001) video calls. However, audio quality was adequate to determine if the instructions were carried out with no dispatchers rating audio as incomprehensible, 0/90 (0.0%, P=0.153).[142] The value of being able to see a situation was acknowledged in a qualitative study of the experiences of 6 dispatchers using video dispatcher-assisted CPR. They indicated that using video allowed them to understand the situation and better manage assistance and guidance.[142] Again, these studies were conducted in the adult settings, but dispatcher-assisted video feedback could potentially improve bystander CPR in children, applying the differing CPR techniques required for children. Therefore, investigation of public use of video conferencing in paediatric resuscitation is required.

Using video as a tool to measure the quality of compressions via the rate was less successful. Movement of the bystander performing CPR was used to calculate the chest compression rate and allow the dispatcher to give feedback based on this calculation. However, the shape and movement of the person (in particular, movement of long hair) significantly impacted results.[143] According to the NZRC[92] adult CPR Guidelines, the compression rate needs to be between 100 and 120 beats per minute. The study which used video to measure compression rate[143] targeted the median of 110 compressions per minute in 30:2 CPR while allowing for an error of ±10 compressions per minute. The algorithm estimated accurately 87.0% of the time for participants with short or tied back hair, 74.0% for those with short to medium-length hair and 55.6% for those with long loose hair. This potential difference in the accuracy of 31.0% based on characteristics of the bystander shows that further research is required.

While video consultation in urgent care is becoming commonplace, mobile video consultation during resuscitation is still emerging, and research to date is predominantly carried out in simulated environments.[144] One study investigated bedside consultations during neonatal resuscitation, initiated via video conference (n = 84). Of these consultations, eight were unable to connect via video conference, 14 were for advanced resuscitation, 15 for respiratory distress and 32 for prematurity.[145] While this study mainly found evidence of increased access to neonatal specialists and reduction in unnecessary transfers, a unique aspect was a survey of teleconferencing participants about the technology (n = 64). While most teleconferences achieved good connectivity, the survey revealed that alongside the eight consultations unable to connect, 20 (31.3%) were able to connect on the first attempt, while 5 (7.8%) lost video connectivity during the consultation. The mean score for the quality of the video was 3.3 (acceptable), using a Likert scale of 1 (poor) to 5 (excellent), with the main problems reported as poor frame rate, poor white balance and insufficient definition.

A 2017 randomised controlled trial in Paris investigated simulated paediatric resuscitation by junior doctors (n = 42), comparing those with an intensivist watching a video feed from Google Glass (GG) and providing real-time feedback with a control group without video intensivist support.[146] The quality of CPR was measured using no-blow (fraction of time when no ventilation occurred), no-flow (fraction of time when no compressions occurred) and the depth and speed of compressions, as well as the effectiveness of ventilation, measured using data from the mannequin. GG-supported physicians reported the video support was "helpful" even though no significant difference was apparent between control and GG groups in no-blow and no-flow fractions. However, the quality of CPR (effectiveness of both ventilation and compressions) delivered in the first five minutes of resuscitation improved.[146] This improvement in CPR technique with GG support is similar to the results of studies described above, where video DA-CPR provided to a bystander improved quality of CPR. However, hands-off time increased.[137-139] Interestingly, the junior doctors with GG support also often paused CPR to listen to video feedback; however, their hands-off time was no different from the control group.[146]

Transmission of data

Electrocardiogram (ECG) acquisition using mobile devices in emergency care is emerging, with reports of support by apps and accessories. Research to validate this approach, however, is minimal.[147] While older studies compared the transmission of ECG via facsimile over a radio or used mobile data with non-commonplace mobile technology[148, 149] in the field, research around using smart devices for ECG acquisition in a healthcare environment remains limited.[147]

One feasibility study, currently in press, reports using an iOS or Android tablet plus an *AliveK* or *Kardia* Mobile ECG (sensor) for screening for atrial fibrillation (AF) in remote Africa.[150] The algorithm used to detect AF correctly identified undiagnosed AF in all four of fifty studied patients. However, more robust research is required to validate this device due to the small sample size. Interestingly, all healthcare professionals in this study reported they had access to personal devices capable of ECG acquisition and were willing to utilise them in providing care, which again shows that access to mobile technology is not problematic for most in the field. Nevertheless, further investigation of mobile data coverage in remote areas may be necessary.

One German study retrospectively examined 314 photographs of on-scene documents, including medication labels, reports from health care professionals, the patient and surroundings, which were transmitted from the ambulance to local physicians, to evaluate the feasibility of an encryption protocol for use in the field.[151] Identifiable content ("good quality") was seen in 240 (76.4%) of the pictures. However, there were some limitations to this study, such as the fact that only photographs taken in daylight hours were included, and that ambulance staff was not provided with a protocol for photograph acquisition. Further research is required around time on scene and patient outcomes or treatment concerning the transmission of data.

Although most research on transmission of data relates to ECG transmission, similar concepts could be adapted to the paediatric population. For example, transmissions could be made of oxygen saturations, heart rate, and photographs of rashes. Further exploration of transmission of paediatric specific health data is required.

Hardware and sensors

Transmission of data via cardiac electrodes and pulse oximeter has been presented as a concept for detection of a heart attack in the adult sector. In 2008 Leijdekkers and Gay[152] introduced the concept of a self-testing application to reduce time to detect and provide appropriate advice during a heart attack. This system relied on the connection of other devices to a mobile phone, for example, a pulse oximeter and electrocardiogram electrodes, which could then be automatically transmitted to appropriate services.[152] While the authors outlined the concept, no information regarding implementation or validation was presented. In 2015, Widick, Talkington, Bajwa and Dantu[153] described a secure networking solution that allowed communication between mobile devices and would have allowed implementation of the above project. Again, no validation or evidence was reported alongside this concept, showing that further development of transmission of data via the internet of things in healthcare is still required.

Documentation

Speech recognition for documentation in resuscitation was investigated in 2004 using *ViaVoice* on portable computer systems in a laboratory and during simulated resuscitation.[154] Findings showed that recognition of phrases was accurate in 75% of phrases used. However, some limitations were apparent, including the need for the physician to complete a task and accurately describe it simultaneously to ensure the correct record of timings; this may have increased cognitive load, affecting decision-making processes.[119] With the evolution of mobile devices and software, further investigation around speech recognition in documentation during resuscitation is required.

Documentation using mobile technology is currently occurring in adult and paediatric resuscitation via an electronic medical record (EMR), which can often be accessed using mobile devices. While technology including the EMR is now an integral part of patient care and provides ease of access to patient information, Grant, Wolff and Adler[155] have suggested that using the technology during resuscitation could negatively impact patient care. This negative impact could be through human factors, for example, through the loss of eye contact, being outside of the immediate resuscitation area or through the increased potential for error.[155]

In paediatric resuscitation, the cognitive load can be increased by the complexity and size difference of the presenting patient.[8, 119] The resuscitation of children is different from the more common one of adults. To mitigate this, Grant, Wolff and Adler[155] have suggested including EMR on mobile devices in simulated learning.

2.6 Conclusion

This scoping review has discussed the current literature regarding the use of mobile technology in resuscitation. The significant gaps in this field of research were identified, including those for paediatric patients. Overarching themes related to improving patient survival and quality of life by using mobile technology were apparent. For example, reducing the time to treatment and increasing the quality of the CPR provided. However, research in this area is currently in the emergent phase, where many solutions require further validation, while in-depth comparison between studies is difficult. This review has also fulfilled a secondary aim, by showing that some resuscitation training and teleconferencing via mobile technology have been evaluated for paediatric patients. However, no studies were found that used mobile technology for weight estimation in paediatric resuscitation at this point. This means that further research on the role of mobile devices in paediatric resuscitation is required.

2.7 Implications

Further research is required about the present and future use of mobile technology to augment resuscitation. Emphasis needs to be placed on paediatric resuscitation. Furthermore, stronger empirical evidence linking mobile technology explicitly with cognitive load and resuscitation decision-making processes is needed to inform future developments. At the time of completing this literature review there was a distinct lack of literature around the use of mobile technology in paediatric weight estimation, showing the need for further research in this field.

3 Chapter Three - Literature Review

(addition on completion of this thesis)

3.1 Introduction

Technology is continually evolving and along with this the literature reporting these advances. As an academic and researcher keeping up to date with current research in your area of research is essential. The literature review (Chapter Two) was completed in early 2017 and since this time technology and literature have also emerged. Therefore, the search strategies utilised in this literature review were replicated at the end of this study March 2019 to ensure that any publications since the original literature review were included in this research.

3.2 Methods

Repeating the search strategy (see section 2.4 for more detail) revealed 14 new articles meeting the previous criteria after duplicates were removed. Two further results were excluded as they were media releases which related to research already included in the search results, leaving 12 studies. One further study was excluded on finding that although the abstract was presented in English, the article itself was not, which left 11 studies for analysis. These studies can be divided into five categories: dispatch, teleconference, training, weight estimation and general.

3.3 General

The review process started with assessing the studies in the general category. The most recent study was a systematic review of interventions to improve the quality of bystander CPR.[156] While the interventions discussed included the use of aids to bystander CPR, which included the use of technology, they were limited and descriptive; for example, they covered dispatcher-assisted CPR (including video conference), real-time feedback devices and a pneumatic ventilator.[156] This shows a trend similar to that of the original literature review in this thesis in that the use of mobile technology in resuscitation is currently sparse, and the literature validating its use is only just emerging.

Similarly, descriptive literature exists around emerging technology in OHCA.[157] The concepts related to mobile technology discussed by Latimer, McCoy and Sayre[157] also relate to dispatching people to an AED to OHCA along with introductions to the delivery of AED via drone and how wearable technology could assist. However, there is no validation of these services, only a description.

One qualitative study investigated the eye-tracking of four expert clinicians during resuscitation to gain insights into their decision-making in such a context.[158] This study identified five key themes: logistic awareness, managing uncertainty, visual fixation behaviours, selective attendance to information, and anticipatory behaviours. The authors plan to utilise this information in the training of clinicians for the resuscitation environment.[158]

3.4 Dispatch

Two studies investigated technology concerning OHCA. The first, set in Copenhagen, Denmark, analysed the access of AED for public use.[159] The authors explored optimised placement and accessibility, finding that the chance of public defibrillation tripled and the 30-day survival rate of those who were defibrillated doubled after the optimisation.[159] It is worth noting that the data utilised in this study were collected between 2008 – 2016, and the AED accessibility may have increased as they became more affordable and part of public first-aid training. A limitation of this study is the inability to determine how much of the change was related to optimisation of AED accessibility or changes in teaching and affordability.

The second study trialled a reengineered smartphone-based dispatch system for trained lay-people to perform CPR or take an AED to a collapse in Stockholm.[160] The performance of CPR by the public in this study was 26%, which is lower than the studies discussed in the initial literature review that reported CPR was initiated in 47% to 62% of OHCA. Unfortunately, patients who suffered an OHCA during the night were not included in this study. Furthermore, data would have been richer if the authors had been able to compare the current system to their previous SMS based system of dispatch.[160]

3.5 Training

Three manuscripts discuss the training of resuscitation skills using technology. Only one of these studies has validated results for comparison. Hong Kong researchers investigated CPR teaching methods in a high school. Three methods of teaching were employed (theoretical only, video with practical and video, practical and real-time device driven feedback).[161] Knowledge of CPR was increased with all teaching methods. However, confidence and quality of compressions were particularly increased when using smartphone feedback.[161] A limitation of this study is that in the school setting, the students were predominantly male and limited to one school, which means results may not be generalisable.

Multi-platform education is currently evolving along with the research validating this. One manuscript describes the development of the *SaveLife* mobile application which aims to enhance hospital clinicians' education around advanced cardiac life support using case studies.[162] This software was developed with a five-step method: analyse, design, develop, implement, and evaluate.[162] However, while a description of the application design and development is included, a substantial evaluation of the software is not specified in the manuscript. Therefore, a study to validate this software would add rigour to the software development process described in this research.

The third manuscript in this section describes a proposed study design for evaluating a multi-platform course in neonatal resuscitation.[163] While the design of the study is robust, peer-reviewed results of the study after it is completed would allow comparison for comparison with related literature.

3.6 Weight estimation using mobile technology

What was initially missing from the literature was the introduction of research on the use of mobile technology in weight estimation for paediatric resuscitation. Since the completion of the literature review chapter, two studies have emerged which partially address this lack of research.

The first study aims to enhance age-based weight estimation by using gender and a visual representation of body habitus using mobile technology.[67] While the addition of body habitus and gender to optimise age and length-based weight estimations is not a new concept,[14, 62, 69, 164, 165] with previous authors digitising this information,[62] the presentation of this on a mobile device with a scalable image to represent body habitus is novel.

This research was tested in a simulated experiment using an existing dataset to compare existing age-based weight estimation formulae and optimise them by utilising Centre for Disease Control (CDC) and World Health Organisation (WHO) weight-for-age data. The authors conclude that adding body habitus and gender to adjusted age-based formulae can increase the accuracy of weight estimation calculated using age.[67] However, they go on to suggest that length-based methods such as their application should be considered more accurate and used instead of age-based methods of weight estimation if possible. The accuracy of length-based methods is backed up by literature published a year earlier applying body habitus, gender, and ethnicity to age-based and length-based weight estimation methods in NZ.[14]

A limitation of this study was that it used an existing UK dataset consisting of 1,070,743 children between 4-5 years of age and 11-12 years.[67] While the dataset is large the gap in children between 6-10 or 13-14 years could limit the generalisation of results. Furthermore, using the application with real-life measurement in children could validate this application and provide more insight into the weight estimation needs of the UK children.

The second study (n = 627) utilises photogrammetry to measure the length of a child using an artefact[166] similar to that discussed in section 5.5 of this thesis. Results show good agreement between the estimated length and measured length of children, a bias of −0.1% (95% CI −0.3–0.2%).[166] However, the study was only tested in a hospital emergency department in non-emergency situations where conditions were static as children were photographed standing upright against a wall if they were old enough to stand.[166] This does not simulate a resuscitation environment where children may be unconscious and likely to be prone or supine.

Furthermore, the applicability of this application to wider populations is unknown, which means this application requires validation in populations that are more diverse than a single centre in Switzerland[166] before the wider adoption of this application could be considered.

3.7 Conclusion

When Chapter Two (the first literature review) was written in 2017, this scoping literature review found no studies that presented mobile applications that used a smartphone camera to estimate the weight of a child at the point of care during paediatric resuscitation. When the literature search was redone in 2019 (completion of the thesis), published literature had progressed and revealed two applications which partially solve weight estimation using mobile technology.

One applications located in the later literature search builds on existing age-based weight estimation by introducing a silhouette of body habitus while the other uses photogrammetry to measure the length of an object or child which could later be converted to a weight based on height. Both studies have limitations, and while there is some overlap with the aim of this study, the context, methodology, testing and parameters are significantly different from the research proposed in this study.

4 Chapter Four - Methodology

4.1 Introduction

This chapter describes the Design Science Research (DSR) paradigm and gives a rationale for the selection of DSR for this study and introduces components of several DSR models and explains the selection of an adaptation of Hevner's DSR[167] process which has been followed in this research.

Before discussing the relationship of DSR with philosophical theories, definitions of key concepts are required. Research has been defined as research a systematic investigation to establish facts and reach new conclusions,[168] connecting this definition with DSR, Vaishanavi, Kuechler & Petter[169] add that in DSR research is an activity that contributes to the knowledge of a phenomenon or artefact. Put more simply the purpose of research is to inform a body of knowledge by using the product of philosophical inquiry that is established through a systematic comparison of facts, theories and ideas. These are then sorted, categorised, analysed and compared to legitimise or validate any new knowledge.[170]

The following section will introduce DSR and explain its relationship with philosophical paradigms and explain why DSR is the optimal platform for this research.

4.2 Design Science Research

4.2.1 Choice of Design Science Research methodology

DSR provides a framework for solving real-world problems and involves a process (series of activities) or product (artefact).[171, 172] The DSR problem-solving paradigm allows knowledge to be validated through research that involves construction, design or creation; furthermore, DSR drives innovation (which is highly valued in society) while providing academic rigour to the innovation process.[167, 173, 174] The focus of this PhD is to develop a mobile application to accurately estimate the weight of a child during resuscitation, with a secondary aim to decrease the ad-hoc adaptation of existing methods of weight estimation. Using a DSR framework will provide the systematic, robust approach required to develop the knowledge and innovation to meet these project goals.

4.2.2 History of DSR

DSR initially emerged in the 1950s and 1960s (first generation of DSR) and, soon after, was rejected as a valid research methodology.[175] In the 1980s and 1990s, Herbert Simon, a pioneer of DSR at that time, suggested that DSR was ignored or rejected by the academic world because it was viewed as a professional activity rather than research.[176, 177] Simon went on to relaunch DSR. He promoted DSR as a way to solve real-world problems through innovation by the construction of an artefact, with the process of design providing validated knowledge. Simon's work allowed DSR to gain credibility in academia.[177]

4.2.3 DSR in relation to traditional philosophy

According to Annas,[170] philosophical "ways of knowing" can be categorised as realism, interpretivism, critical theory, phenomenology, hermeneutics, constructivism and positivism. These philosophical paradigms all relate to how existing objects or phenomena behave or interact. However, Simon[177] explained that these paradigms did not allow for knowledge acquisition through the design or creation of artefacts, and, therefore, none could be applied to DSR. For example, applying a positivistic lens suggests that valid or true knowledge leads to understanding, which can allow prediction of behaviour related to a phenomenon.[169, 170] While positivism validates many phenomena, it assumes a phenomenon already exists and is ready for examination. However, if a phenomenon does not already exist, traditional positivistic ways of creating, sorting and interpreting knowledge cannot be applied to gain understanding. What this means is that DSR does not fit with traditional philosophical paradigms as DSR requires the creation of a new phenomenon to inform knowledge.

Early adopters of DSR such as Simon[176, 177] and Levy[178] asked the question: If a phenomenon or artefact does not naturally exist, and we create or design said phenomenon and seek to understand its creation, is this science? Both authors argued that DSR was a scientific paradigm that allowed us to understand new forms of human activity and was, therefore, both scientific and technological. Levy[178] explained that natural science mostly produces answers to "what" and "how", and suggested that DSR involved knowing "why" and giving purpose to a newly created artefact or process.

Similarly, but more recently, the business world has begun to value the "why" of DSR and apply it to the communication of innovations using the Golden Circle approach (Figure 5 - Successful design in business communication). This approach was described in 2009 during a TED Talk by Sinek[179] suggested that much communication, knowledge and design used in advertising was communicated by explaining "what" and "how". He suggested thatcommunication was made more successful by adding "why" to this construct and that communication should begin with "why" rather than "what" or "how" when discussing or advertising innovations (Figure 5). This is similar to the way that Levy[178] extended natural science with design science in his work, by valuing the journey to innovation through understanding the design process.

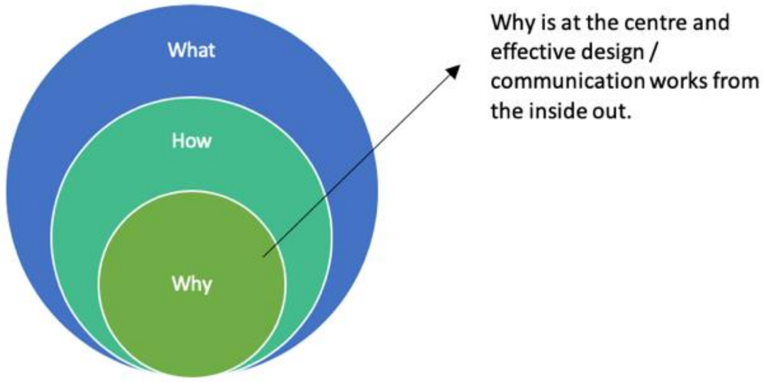


Figure 5 - Successful design in business communication[179]

4.2.4 Position of DSR as a science

Positioning DSR amongst other sciences can be problematic because DSR deals with a new, “unnatural” paradigm which has not historically been embedded in natural science. In order to illustrate the position of DSR among other sciences, Owen[180] created a graph which represented various scientific paradigms on two axes, with the dimension-spanning, symbolic plotted against real research and the analytic plotted against synthetic research similar to that plotted in Figure 6. He claimed DSR was the most synthetic paradigm. Synthetic disciplines build their knowledge base while creating or inventing artefacts and therefore, DSR can be considered an artificial science.[180]

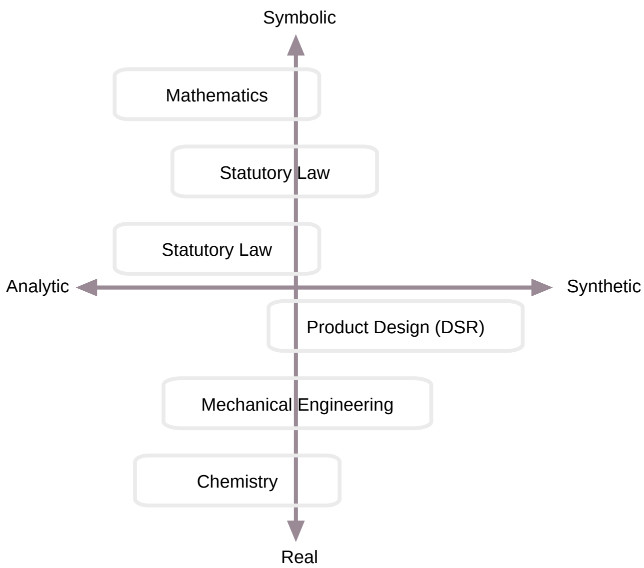


Figure 6 - Map of scientific paradigms[180]

Thus, DSR is concerned with creating a phenomenon or artefacts to solve a real-world problem, making this methodology an appropriate choice when designing software solutions such as the one described later in this thesis.[181] Hevner[167] refined the DSR process in 2007 by associating it with the pragmatic paradigm. Iivari[182], however, argued that pragmatism implied truth and utility, which he believed DSR did not achieve. In Iivari’s view,[182] pragmatism meant an artefact existed and has a purpose. However, he questioned whether existence in the mind equated to the body of existing knowledge associated with pragmatism. This assumption within pragmatism seems to devalue the knowledge gained during the development of the artefact. Therefore, for this reason, I agree with Heavner's claim [167] that DSR may not sit well within the pragmatist paradigm.

In a 2017 revision of their 2004 work, Vaishnavi, Kuechler and Petters[169] suggested that research involving the development of information technology was multi-paradigmatic, implying that alignment with traditional philosophical concepts can be fluid. One theory from their work stood out; this was that DSR could complement positivist, interpretive, and critical perspectives rather than being merely a component within any of these. With this in mind, if the DSR paradigm was considered the artefact (artificial), it could be argued that recognition of placement outside of traditional perspectives could validate the placement of DSR as a stand-alone philosophical paradigm.[169]

The initial focus had been on the contribution of the environment and body of knowledge to the artefact. A second issue was the challenge of ensuring society recognised that the development of the artefact was research and as contributing to a body of knowledge.[183] DSR theory has evolved to meet this need by emphasising context while providing rigour, process and academic frameworks that make these relationships overt.[183-185] One could argue that DSR is multi-paradigmatic and therefore allows the freedom and creativity that traditional philosophy values.[170] Bearing in mind Gregor & Hevner's suggestion in 2013[183] also recognised the importance of freedom and creativity and suggested that there should be equal emphasis on design, knowledge and context surrounding an artefact. I believe DSR fits well within software design and development and is an appropriate paradigm for this doctoral research project.

4.2.5 Comparison of DSR models

Many DSR methodologies exist today, and each has advantages and disadvantages. Table 10 gives an overview of the objectives of influential DSR methodologies. The development of DSR over time is apparent; for example, academic rigour has emerged over time beginning in 1984 with Archer,[186] who did not include evaluation, through to Iivari,[182] who added structure to the rigour component of Hevner's model.[167] What appears to be missing in later DSR methodologies is planning for the dissemination of knowledge or findings. While it would be easy to assume that this is a part of a separate process, the overt inclusion of dissemination in the DSR process would ensure the robust nature of the research process. With this in mind, this study will utilise an adapted version of Hevner's DSR methods[167] with the inclusion of aspects from other authors such as Iivari's structure,[182] for assuring rigour, and Archer's[186] planning of dissemination or communication of knowledge acquired in the design science process.

Table 10 - Overview of DSR methodologies (adapted from Peffers, Tuunanen, Gengler, Rossi & Hui in 2006[187])

Objectives for a DSR Model	**Archer (1984)[186]**	**Takeda, Veerkamp, Tomiyama and Yoshikawa (1990)[188]**	**Nunamaker, Minder, Purdin (1990)[189]**	**Walls, Widmayer & Sway (1992)[172]**	**Hevner, March, Park and Ram (2004)[184] and Hevner (2007)[167]**	**Iivari (2007)[182] applied addition to Hevner (2007) [167]**
Real-world problem was identified	Analytical: Programming, Data collection	Awareness of a real-world problem	*** implied ***	*** implied ***	Relevance Cycle: identify a real-world problem and	
Design theory development			Theory Building: Conceptual Framework, mathematical model	Kernel theories		
Objectives identified				Meta-requirements	Relevance Cycle: Identify requirements and acceptance criteria	
Artefact designed and developed	Creative: Analysis, Synthesis, Development	Suggestion for solution, Development	Systems Development: Prototyping, Product Development, Technology Transfer	Design method Meta design	Design Cycle: Design, create and test the artefact	
Experimentation, Demonstration or simulation.			Experimentation: Computer Simulations, Field Experiments, Lab Experiments			
Formal Evaluation and conclusion		Evaluation, Conclusion	Observation: Survey, Field and Case Studies	Testable design process, product hypotheses	Rigour Cycle: expertise, existing solutions	Rigour: Practical problems and opportunities, Existing artefacts. Analogies and metaphors, Theories
Dissemination of research and artefact	Executive: Dissemination of knowledge				Communication was included in early work but not a focus in 2007 adaptation	

4.2.6 Adaptation of Hevner’s DSR model

Hevner, March, Park and Ram’s original research guidelines (H-DSR) in 2004 depicted H-DSR as sequential steps.[184] However, Hevner's later research in 2007 introduced the cyclic nature of his approach more overtly.[167]

In his 2007 work, Hevner proposed a model (Figure 7) that identified the relationship of DSR with the environment and existing knowledge in order to place DSR alongside traditional research while giving equal emphasis to relevance, design and rigour.[167] The cyclic nature of his revised research model included three cycles (relevance, design and rigour), which again emerged sequentially.[167] However, later research pointed out that a linear sequence was not essential and suggested that movement amongst cycles and sub-cycles could enhance the DSR process.[185] Thus, for example, if an issue arises during development, this study will either begin the cycle again or even switch cycles and begin again at the relevance cycle to allow development to progress. In other words, the three cycles of H-DSR may occur concurrently or out of sequence, which is the approach adopted for this PhD. However, one potential difficulty will be tracking the position of each cycle throughout this PhD; furthermore, paying attention to this will ensure completion of all components in H-DSR cycles.

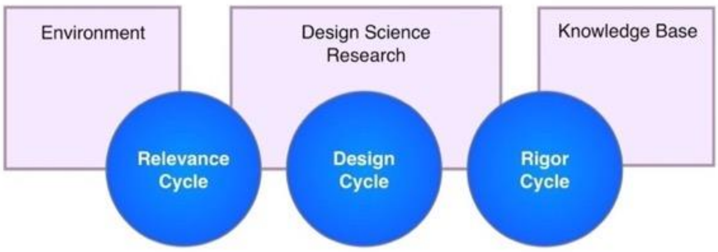


Figure 7 - Hevner's model to connect DSR with the environment an existing knowledge[167]

H-DSR was selected for this study as it has some distinct advantages over existing methods of software design, such as the “build and fix” approach.[167] Accordingly, H-DSR includes an examination of the users’ needs, which adds context that may not be addressed up-front using the “build and fix” method. A further advantage of H-DSR is the provision of a rigour cycle to ensure that the knowledge acquired is robust and valid. However, Iivari[182] believes that Hevner’s[167] rigour cycle would benefit from further structure and suggests using the following headings within the H-DSR rigour cycle: “Practical problems and opportunities”, “Existing artefacts (solutions)”, “Analogies and metaphors”, and “Theories”. While these headings may add structure and academic process, user experience was missing. Therefore, this study adopts a blend of Hevner’s[167] original H-DSR with some of Iivari’s[182] headings to provide a more overt inclusion user experience and its analysis. By including user experience in the rigour cycle, this ensures that user experience weighted similarly to other sources of information such as existing solutions, academic material and evaluation of the artefact by developers, in this way user experience provides rigour by its inclusion in this cycle.

4.3 Methods

4.3.1 *Research aim*

Design, build and test an application that will return an accurate weight (and therefore body surface area) estimate for NZ children in multiple environments. The user interface will be straightforward with weight estimates tailored to NZ children, by using NZ-specific data and demographic characteristics of children to increase the accuracy of weight estimates.

4.3.2 Initial acceptance criteria

To achieve this, the initial acceptance criteria (Table 11) were determined by the developer to achieve the research aim above using the resources (such as an iPhone) the developer owned. It is worth noting that the acceptance criteria may be refined based on findings throughout the design science process such as the development, consultation and testing process.

Table 11 - Initial Acceptance Criteria

Initial Acceptance Criteria	
1	Mobile initially for iOS operating system
2	Estimate weight for > 75% of population to within 10% of their actual weight
3	Demographic characteristics: to increase accuracy
4	Based on the NZ dataset to increase accuracy
7	Minimal and simple user interface
8	Works in varied environments (such as differing surfaces and lighting)

4.3.3 Blended DSR model

To ensure logical structure for this thesis and that the methods utilised in the design and development of the WEWW application are overt, Figure 8 depicts the blended version of the DSR process, with clear links to Hevner's initial cycles. The nature of the blended design means that the developer can move between cycles and sub-cycles freely. This freedom poses a trade-off situation: for example, the dynamic and exploratory nature of this research is challenging to replicate, and it could be lost when presented, examined and reported traditionally. On the other hand, the dynamic nature of the blended DSR model could be considered less constraining; however, in non-traditional presentation the dynamic movement between cycles may be difficult to follow. Therefore, this thesis will adopt the headings used in the blended model (Figure 8) to make the links more overt with the knowledge that movement between cycles will be less overt in this method of presentation. For example, Chapter Five – Prototyping and Experiments uses the design cycle and the headings "Design", "Implementation", "Testing" and "Evaluation" from the blended model. Similarly, the relevance cycle can be seen through the continual revisiting of the real-world problem, with its analysis and evaluation leading to the acceptance criteria being reformulated three times, based on information that arises throughout the DSR process utilised in this thesis.

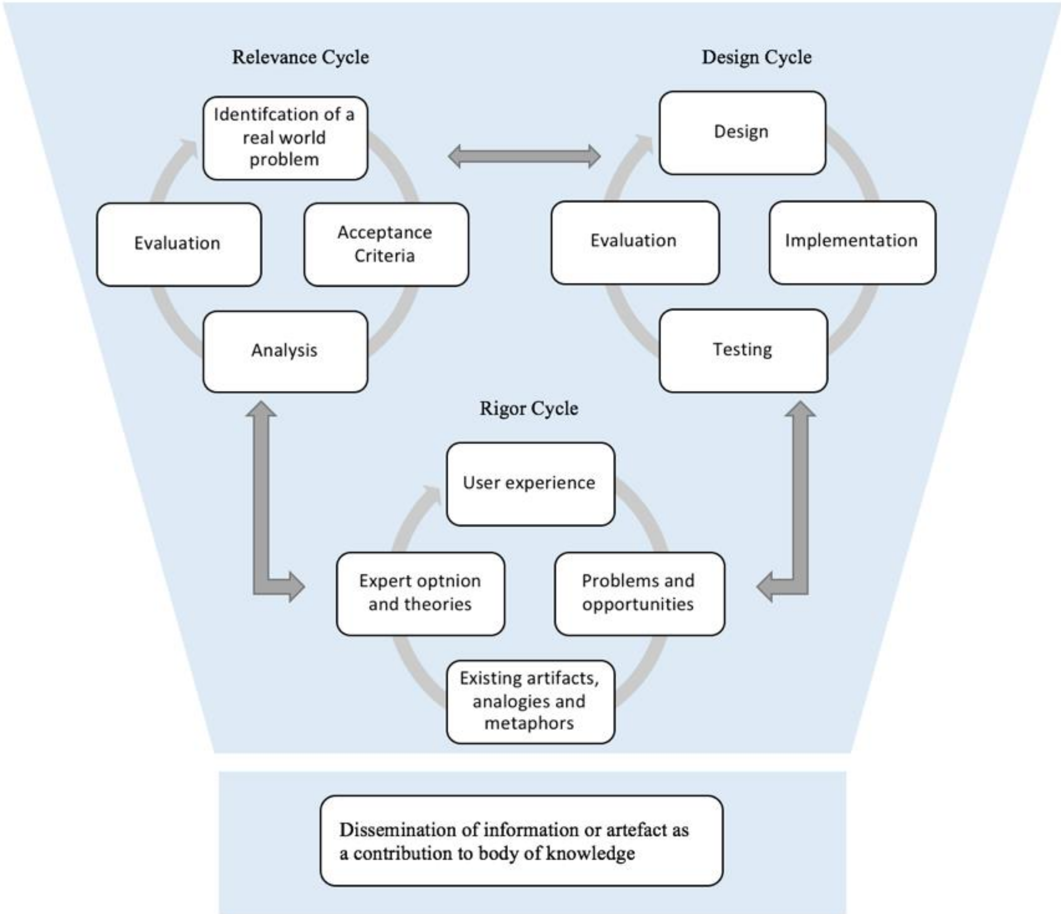


Figure 8 - Blended DSR model used for this research

In a traditional thesis as defined by Auckland University of Technology[77], the methods would either be presented as a part of this methodology or as a separate chapter after it. However, as the blended design science approach utilises many methods (Table 12), each of them will be explained and discussed at the time it becomes necessary in the process. For example, Chapter Five – Prototyping and Experiments, presents a series of experiments that are similar to the hypothesis testing of traditional scientific experimentation while Chapter Seven - Testing utilises traditional data collection and presentation of descriptive statistics. A breakdown of the relationship between sections of this thesis and the blended DSR model used for this research is shown in Table 12.

Table 12 - Relationship between blended DSR approach and the structure of this thesis

Chapter		Section	Method	Design Cycle
1	Introduction		Description and use of literature to validate the problem that was identified	Relevance Cycle (Identification of a real-world problem, analysis) and Rigour Cycle (Expert opinion and theories)
2	Literature Review		Joanna Briggs method for systematic literature reviews	Rigour Cycle (Existing artefacts, analogies and metaphors)
3	Methodology	Acceptance criteria	Determining the user acceptance criteria	Relevance Cycle (User acceptance criteria)
		Design science research	Discussion and critique of DSR in relation to this research	Rigour Cycle (Existing artefacts, analogies and metaphors) Relevance Cycle (Analysis)
4	Prototyping and Experiments	Aspects of mathematical proof of concept	Description of experiments testing potential solutions using Design Cycle headings fromFigure 8 - Blended DSR model used for this research	Design Cycle (Design, implementation, testing, evaluation)
5	Application Design and Development	Design considerations	Description of the rationale for design decisions and updating of the acceptance criteria	Relevance Cycle (Analysis, user acceptance criteria) and Rigour Cycle (Problems and opportunities, expert opinion and theories)
		Implementation	Design and development of the WEWW application with updating of the acceptance criteria	Design Cycle (Design, implementation, testing, evaluation) Relevance Cycle (User acceptance criteria)
6	Testing	Testing design	Consultation regarding data set size	Rigour Cycle (Expert opinion and theories)
		Ethics	Consultation with Ethics Committee and Maori consultation	Rigour Cycle (Expert opinion and theories)
		Beta testing	User acceptance, observation and think aloud	Rigour Cycle (User experience)
		Alpha testing	Analysis of accuracy	Relevance Cycle (Analysis)
7	Discussion	Whole Chapter		Rigour Cycle (Expert opinion and theories) Relevance Cycle (Analysis, evaluation)
		Evaluation	Comparison with acceptance criteria	Relevance Cycle (Acceptance criteria, analysis, evaluation)
		Limitations	Overview of limitations of this research	Rigour Cycle (Problems and opportunities)
		Implications and future research	Future research and implications for practice	
8	References			
9	Appendices	Appendix A	Contract with Statistics NZ	Rigour Cycle (Expert opinion and theories)
		Appendix B	Verification of consultation with Maori	
		Appendix C	Ethics approval after consultation with the Ethics Committee	
		Appendix D	Information Sheets	
		Appendix E	User Testing Data	Design Cycle (Design, implementation, testing, evaluation)
		Appendix F	Code for the WEWW application along with UML Diagrams	

4.4 Chapter Summary

This chapter has introduced DSR and explained how DSR is placed within other sciences and interacts with philosophical concepts. A comparison of DSR models was presented with a more in-depth discussion on Hevner's three-cycle approach[167, 184] with an overview of the adaptation of his approach for this research.

The aim of this study was stated, and initial acceptance criteria were identified while the final table gives an overview of the thesis structure and illustrates how the content of chapters relates to the blended DSR model selected for this research.

5 Chapter Five – Prototyping and Experiments

5.1 Introduction

This chapter will present pre-software development experiments which guided the decision making and choice of solutions during software development. Firstly, the aims of this research are revisited. Followed by a series of experiments (Figure 9) where each experiment will be presented using the headings within the Blended Design Science Research (DSR) in methodology (Design, Implementation, Testing and Evaluation) which are shown in section 4.3.3 of this thesis.

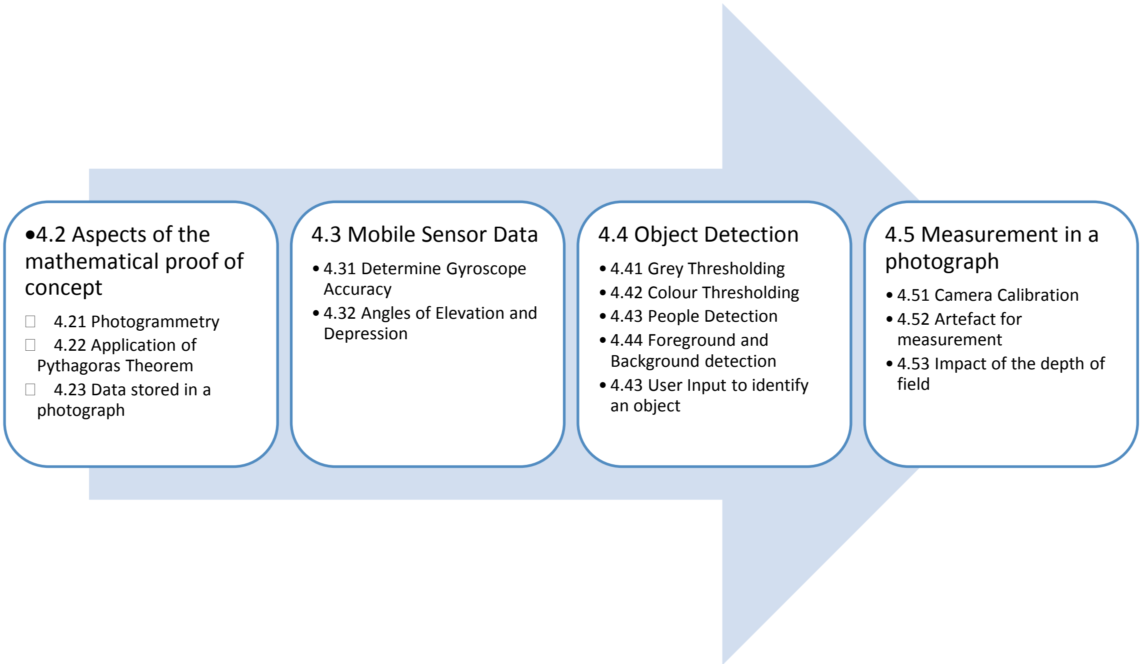


Figure 9 - Overview of experiments in Chapter Four

The chapter summary will indicate which methods tested in the experiments will be utilised in software development and outline a refined set of acceptance criteria.

5.1.1 Revisiting the purpose of this study

As illustrated in previous chapters, providing lifesaving treatment is often time-critical and complex with treatment decisions made in high stress and chaotic environments.[8, 79] These factors, along with the need for prompt treatment, patient information and the possibility of unanticipated events could increase the potential for error and cognitive load for clinicians.[8, 79] Providing an application to assist in this situation is complex and requires consideration of many aspects of clinical practice, such as the speed that a weight estimation is required, as well as the chaotic and variable environment, along with the constantly changing resuscitation environment whilst translating this into a solution using mobile technology.

While working in a dedicated paediatric Emergency Department (ED) where resuscitation of children occurred regularly, three aspects appeared to influence the accuracy of the weight estimation process that the Weight Estimation without Waiting (WEWW) application needs to address. These were, the diverse demographics of the children, the ad-hoc adaptation of weight estimation methods and the inaccuracy of existing tools available for weight estimation. Figure 10 - Factors in practice that appear to contribute to inaccurate weight estimation

shows how these factors can culminate to lead to inaccurate weight estimation.

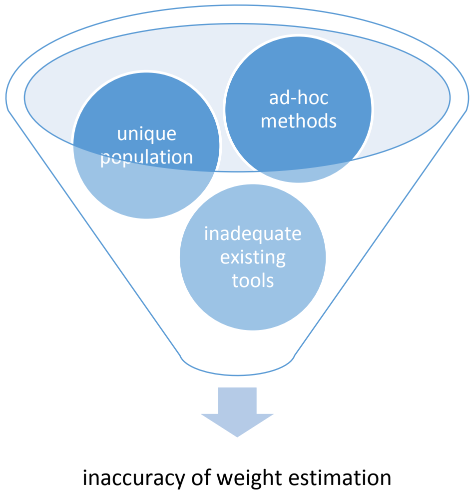


Figure 10 - Factors in practice that appear to contribute to inaccurate weight estimation

Two of the factors in Figure 10 - Factors in practice that appear to contribute to inaccurate weight estimation

that affect the accuracy of weight estimation in paediatric resuscitation have been investigated in New Zealand (NZ) research. Two studies recognised the diversity of the NZ population and inaccuracy of existing tools and provided an alternative weight estimation technique that considered demographic characteristics.[14, 16] However, the focus of these was on non-technology solutions that required human decision-making processes. Such as the judgement of body habitus, which adds subjectivity and may increase cognitive loading in an already stressful situation. With this in mind, mobile technology could reduce subjective human decision in the weight estimation process to give consistent results.

One of the first steps in designing mobile technology intended to streamline workflows, decreasing the need for subjective decision making which could improve the accuracy weight estimation during resuscitation was to investigate existing solutions. A scoping literature review (Chapter 2 and 3) highlighted significant gaps in research involving mobile technology in resuscitation, particularly for paediatric patients. New research in this area is emerging with mobile technology being developed for use in resuscitation (e.g. training and teleconference assessment for paediatric patients). However, no studies using mobile technology in resuscitation for weight estimation were available at the inception of this study. This lack of existing solutions shows the need for further research on the role of mobile devices in paediatric resuscitation. Furthermore, it illustrates that there is currently no mobile technology used to estimate the weight of a child during paediatric resuscitation.

With the advent of mobile technology such as smartphones and tablets with a built-in camera, the ability to use computer vision at the point of care could make these devices a viable platform for the development of a weight estimation tool for use in resuscitation environments. Before the development of a solution, proof of concept occurred in the form of a series of experiments shown earlier in this section (Figure 9).

5.2 Aspects of the mathematical proof of concept

5.2.1 Photogrammetry

The usefulness of photography in medicine was first published in 1839 when the Daguerre process (silver dusted plate exposure) made photography more affordable and less complicated and led to the introduction of photography as a tool in medicine.[190]

Photogrammetry is the measurement of angles and distances in photographs, and this process was first published in 1907,[191] where photogrammetry techniques were used to measure crystals. Today, close-range photogrammetry techniques are applied in many fields, such as forensics, cellular biology and agriculture to determine dimensions of objects via image analysis.[192]The application of photogrammetry in medicine rapidly emerged in the 1970s. For example, in 1979[193] a study used photogrammetry to determine the measurement of wounds (leg ulcers) using two cameras on different angles (stereo-photogrammetry).

Despite photogrammetry being well established in medicine today, no research emerged during the initial Chapter Two – Literature Review illustrating the use of photogrammetry in emergency resuscitation. Yet photogrammetry potentially provides two distinct advantages over traditional methods for measuring stature as it provides results faster with better consistency and interrater reliability than traditional measures.[194-196]

A simple application of photogrammetry is to measure the height of an object in a photograph which can be achieved through measurements and the use of mathematical formulae. Applying this to weight estimation, the height could then be converted to a weight estimate which literature already shows is more accurate than age-based calculations currently endorsed by the NZ Resuscitation Council (NZRC) and St John Ambulance.[18, 36, 66]

5.2.2 Application of Pythagoras Theorem in photogrammetry

One example of using photogrammetry is to measure distance, through the application of Pythagoras Theorem.[197] This theorem was used to calculate the height of an object in a photograph and is commonly used in satellite or aerial photography and city planning.[197] An equation based on the angle of elevation and depression is used to determine the size of an object in a picture by segmenting this into triangles and applying Pythagoras Theorem to determine missing values. If applied in resuscitation this could ultimately determine the height of the child, which could then be converted to an estimate of weight.

5.2.3 Design

Using Pythagoras Theorem (Equation 1) to work out the length of one side of a triangle provided we have all other measurements will assist in measuring the height of a child, and later a weight estimate can be derived from the height.

Equation 1 - Pythagoras Theorem

$$c = \sqrt{(a^2 + b^2)}$$

Application of Pythagoras Theorem to the measurement of a child was simulated using a mannequin with known distances from the camera to the floor and the camera to the mannequin.

5.2.4 Implementation

The following calculations will derive the child's weight estimate. The area between the camera and subject was split into three right angle triangles as shown in Figure 11.

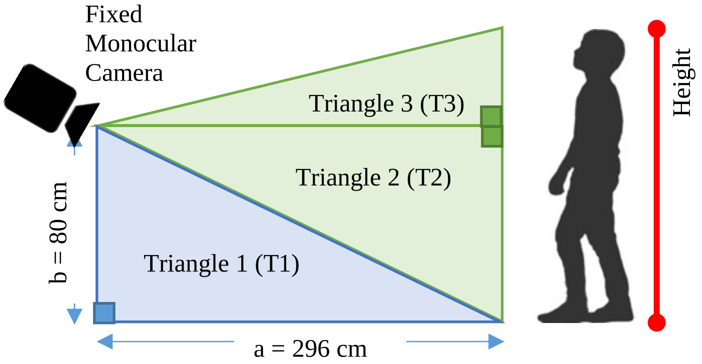


Figure 11 - Representation of using Pythagoras Theorem to missing data

This experiment was set up in an environment where the camera was 296 cm away from the child and 80 cm from the ground to the centre of the camera lens (Figure 11, Figure 12 and Figure 13). Please note that these measurements will be applied throughout this chapter to illustrate mathematical concepts.

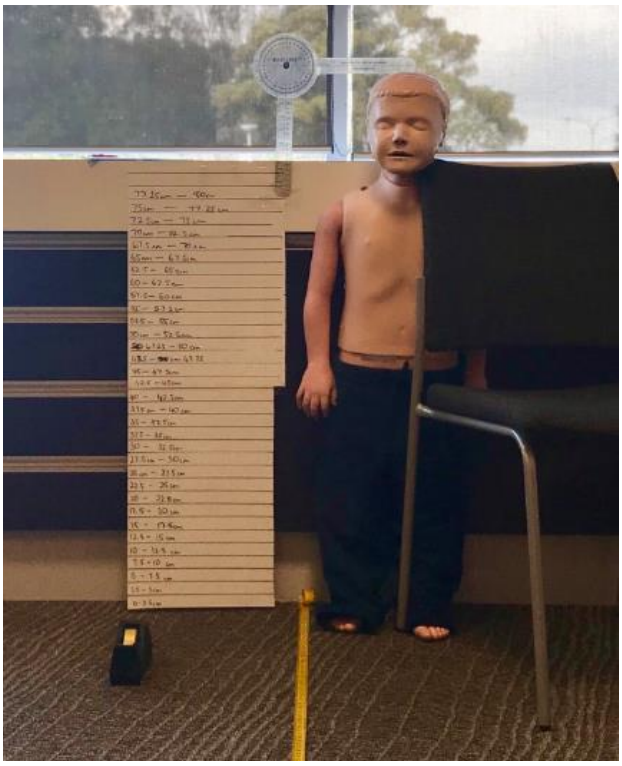


Figure 12 - Mannequin setup for testing Pythagoras theory for height

Figure 13 - Upper and lower measures of mannequin (height) = 107 cm

5.2.5 Testing

Equation 2 and Figure 14 show that the length of edge c can be derived in Triangle One (T1) and Triangle Two (T2) from our existing measurements, the height of camera – T1 b and distance to the child – T1 a.

Equation 2 - Application of Pythagoras Theorem -

$$T1 \text{ and } T2 \; c = \sqrt{(a^2 + b^2)}$$
$$T1 \text{ and } T2 \; c = \sqrt{(296^2 + 80^2)}$$
$$T1 \text{ and } T2 \; c = \sqrt{(87616 + 6400)}$$
$$T1 \text{ and } T2 \; c = 306.62$$

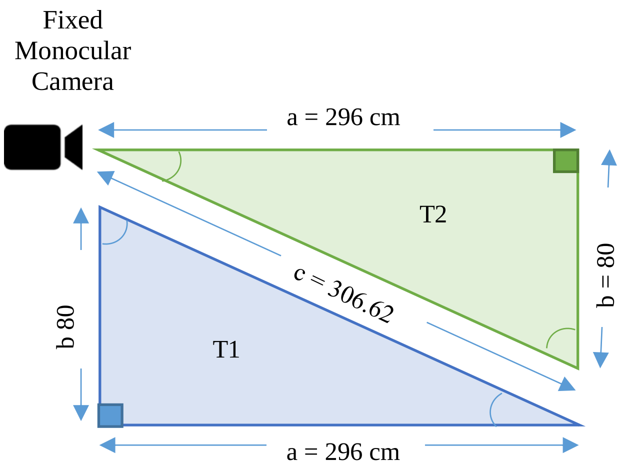


Figure 14 - Application of Pythagoras Theorem

The calculation of Triangle Three (T3) side b using Equation 3 and Figure 15 is not possible without knowing the height of the child before calculation. Two sides of the T3 are missing; these missing data illustrate the complexity of using photogrammetry and Pythagoras Theorem alone to measure distances in an uncontrolled environment similar to that of paediatric resuscitation where distances and measures will continuously change to meet the needs of the resuscitation.

Equation 3 - Pythagoras Theorem for Triangle Three (T3)

$$T3\ c = \sqrt{(a^2 + b^2)}$$
$$T3\ c = \sqrt{(296^2 + b^2)}$$

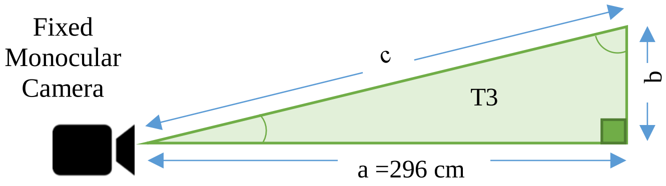


Figure 15 - Application of Pythagoras Theorem to T3

Being aware of the height of the child in the photograph (T3 b + T2 b = 107 cm) Equation 4 calculation would be possible using the equations in Figure 16 via a fixed camera and known distances to the child.

Equation 4 - Pythagoras Theorem for T1, T2 and T3

$$T1\ c\ \&\ TB\ c = \sqrt{(T1\ a^2 + T1\ b^2)}$$
$$T1\ c\ \&\ TB\ c = \sqrt{(296^2 + 80^2)}$$
$$T1\ c\ \&\ TB\ c = \sqrt{(87616 + 6400)}$$
$$T1\ c\ \&\ T2\ c = 306.62$$
$$T3\ b = height - T2\ b$$
$$T3\ b = 107 - 80 = 27$$
$$T3\ c = \sqrt{(a^2 + b^2)}$$
$$T3\ c = \sqrt{(296^2 + 27^2)}$$
$$T3\ c = \sqrt{(87616 + 729)}$$
$$T3\ c = 297.23$$

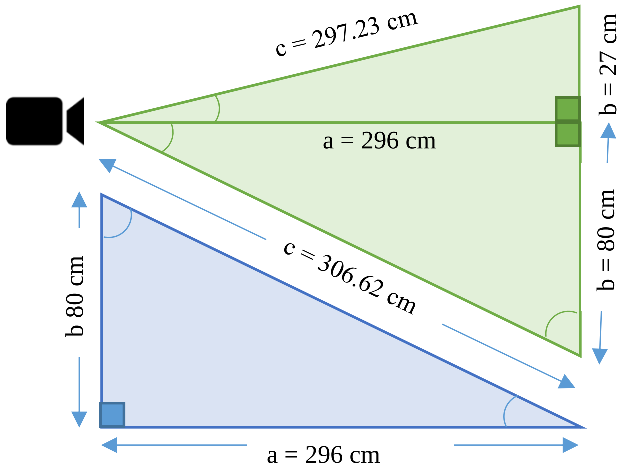


Figure 16 - Pythagoras Theorem for T1 and T2

5.2.6 Evaluation

Pythagoras theorem can be applied easily to the measurement of an object provided that the length of two of the sides of the triangle are known. Applying this to a real-world situation requires knowing the height of the camera and distance to the child with the camera in a fixed position.

In some situations, known distances could be utilised; however, in many situations' distances are not known or able to be measured. For example, mounting a camera to the roof or wall to calculate distance assumes that the environment we measure within is static which is often not the case.

During resuscitation in both prehospital and hospital emergency care the environment varies. Ambulance and other emergency service vehicles have variable internal configurations depending on the model, purpose and age of the vehicle, the service provider the size of the patient and equipment carried. In some circumstances mounting a camera may be possible and a child who was able to follow instructions Pythagoras theorem could be used to calculate the height or measure a child. In practice, resuscitation invokes uncertainty, multiple people, situations and emergencies[198] as well as the need for weight estimation making application of Pythagoras theorem complex.

Therefore, the mobile application designed in this research must be able to adapt to the environment. For example, the layout of an ambulance or at a patient's home are unique and a static environment is not always possible. This means that fixed position cameras or trigonometry that relies on known measurements will not suit this environment. Furthermore, during resuscitation in the hospital, the environment is also required to be adaptable. For example, the height and tilt of the bed are adjustable, and most equipment is mobile to streamline medical treatment.

While mounting a camera within the resuscitation environment may solve the issue of determining the distance to the patient, this would mean that staff would need to create a static environment which could, in turn, add extra work and cognitive load. Furthermore, the time taken to set up the environment for measurement could impact the survival or quality of life for the child receiving resuscitation. Therefore, other methods of determining the distance to the child need to be implemented to make the use of Pythagoras Theorem a viable solution for inclusion in the WEWW application design.

One solution is that data could be obtained by using an external instrument to measure a distance, such as a laser measuring tool. However, this means that staff are required to carry and use extra equipment. With simplicity and cognitive load in mind, it is preferable to use a single device that is already available; therefore, a camera built into a mobile device that is carried by staff and already present is optimal (e.g. smartphone or tablet).

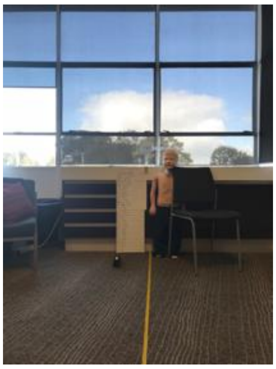
5.2.7 Data stored in the photograph

With the advent of digital photography, data about the camera and photograph environment is often hidden within the header of the photograph and accessing this may be able to assist in photogrammetry calculations. This data is called Exchangeable Image Format File (EXIF).[199, 200]

5.2.8 Design

This experiment will utilise the built-in sensor height of the smartphone camera stored in the EXIF header data in subsequent calculations. Calculations will return the distance to and height of the object in a photograph that is to be measured. An Apple iPhone 7 was used to take a photograph which produced the associated EXIF data shown in Table 13.

Table 13 - EXIF data from the photograph below.

Camera-Specific Properties: Equipment Make: Apple Camera Model: iPhone 7 Camera Software: 11.0 **Sensing Method**: One-Chip Colour Area Focal Length (35mm Equiv): 28 mm 	Image-Specific Properties: Image Orientation: Top, Left-Hand Horizontal Resolution: 72 pi Vertical Resolution: 72 dpi Exposure Time: 1/100 sec F-Number: f/1.8 Exposure Program: Normal ISO Speed Rating: 32 Lens Aperture: f/1.8 Brightness: 5.3 EV **Exposure Bias**: Tab problem for 0 ArtefactEV Metering Mode: Pattern **Flash**: No Flash, Compulsory Focal Length: 3.99 mm Image Width: 3024 Image Height: 4032 **Rendering**: Unknown Exposure Mode: Auto White Balance: Auto Scene Capture Type: Standard **Latitude**: S 36° 47' 53.75 **Longitude**: E 174° 45' 25.65 **Altitude**: 12.23 m **Time (UTC)**: 23:16:59 **Date (UTC)**: 2017:08:14	Other Properties: Resolution Unit: i Exif IFD Pointer: 192 Exif Version: 2.21 **Image Generated**: 2017:08:15 11:17:05 **Image Digitized**: 2017:08:15 11:17:05 Meaning of Each Comp: Unknown Shutter Speed: 1/100 sec **Subject Area**: 1783, 1154, 133, 133 DateTimeOriginal Second Fraction: 542 DateTimeDigitized Second Fraction:42 Scene Type: Unknown Latitude Reference: S Longitude Reference: E Altitude Reference: 0 GPS Speed Reference: km/h GPS Image Direction Ref: True North GPS Dest Bearing Ref: True North

Equation 5 includes the sensor height of the camera that is calculated using EXIF data.[201] This equation can then be used in further calculations to determine the distance to the subject in a photograph.

Equation 5 - Distance to object in an image using EXIF data and sensor height

$$distance\ to\ object\ (mm) = \frac{focal\ length\ (mm)\ \times\ object\ height\ (mm) \times\ image\ length\ (pixels)}{object\ height\ (pixels) \times\ sensor\ height\ (mm)}$$

5.2.9 Implementation

To achieve this, an experiment was set up using the mannequin and data shown in the photograph in Table 13. The EXIF data in Table 13 was inserted into Equation 5 along with data shown in Table 14 to determine the distance to the child or object being measured. The Apple iPhone 7 is reported to have a 1/3” sensor size of 4.8 mm x 3.6 mm (6.0 mm diagonal).[201]

Table 14 shows the measurements used in subsequent equations.

Table 14 - Known measurements used in subsequent equations

Variable Name	Source	Notes	Value
Object height (mm)	Measured	Height of child/mannequin	107 cm (convert to mm)
Object height (pixels)	Computed	Object height in Pixels	1193 pixels
Distance	Measured	Distance from camera lens to subject	296 cm
Height of camera	Measured	Distance from the camera lens to ground	80 cm
Sensor height	Apple Specifications	Height of sensor in mm	3.6 mm
Focal length	EXIF Data	Focus	3.99
Image length	EXIF Data	Height of the photograph in pixels	4032 pixels

5.2.10 Testing

Application of the information in Table 14 using Equation 5 can be seen in Equation 6.

Equation 6 - Applying existing data to determine distance to the object

$$distance\ to\ object = \frac{3.99\,mm \times 10700\,mm \times 4032\,pixels}{1193\,pixels \times 3.6\,mm} = 30060\,mm = 300.60\,cm$$

5.2.11 Evaluation

Camera sensor height has successfully been used in photogrammetry and is a valued measure as it is repeatable and accurate for use in calculating distance.[202, 203] While the sensor height of the camera and other values in the EXIF data can be used to calculate some missing values the subsequent calculation still requires the actual dimensions of the child being measured.[204, 205] This means that further information is still required to use EXIF data in calculations successfully. A further disadvantage this method is that it is a calculation, any equations can increase the risk of introducing errors and subsequent equations can cause a compounding error that could have an impact on the treatment that a child receives.

Again, mounting a camera at a fixed distance in the resuscitation environment could provide a possible solution. However, this would mean that the parameters of the WEWW application need to change for each make or model of ambulance, each resuscitation area in a hospital or each time the resuscitation environment is adjusted. With user input and precise setting up of the resuscitation environment this variability could be overcome. However, precise setup and maintaining a static environment could increase cognitive load and time required during resuscitation and therefore, affect survival and quality of life for the child receiving treatment.

In designing an application which will work across multiple situations and technology, sensor height (used in the above calculations) will vary from device to device requiring calculations to ensure portability of the application. The use of subsequent calculations brings a risk of compounding error in results while increasing the risk of the inaccuracy of weight estimates.

For the purposes of this study no more than 10% error[14, 16, 17] between actual and estimated weight is acceptable, from all sources of error.

A potential solution could use known sized objects (such as the bed) in the room to determine measurements in a photograph. This approach relies on standardised equipment which is not the case in New Zealand emergency care environments. For example, many models of hospital bed or ambulance stretcher exist for different purposes, and each model differs slightly between suppliers in size and functionality.[206, 207]

As an example, during the time I worked in the paediatric ED, there were five concurrent models of bed, three of which were situated in the resuscitation area. During treatment, these beds were often moved, lowered and raised, tilted or manipulated to provide optimal patient care. The requirement for flexibility of the environment and equipment, staff actions and patient response mean a fixed camera is not a feasible solution because the formulae above assume that all aspects of the child are a fixed distance from the camera.

5.3 Mobile sensor data

An alternative method of obtaining missing data for calculation of the height of a child could include using the angle of depression and elevation to calculate the height of a child. However, before this can be implemented, the accuracy of the gyroscope in the mobile device used to obtain these angles needs to be validated.

5.3.1 Determine the accuracy of the gyroscope

The goal of this experiment is to determine whether the gyroscope in the smartphone can give an accurate representation of the pitch of the camera when taking a photograph.

Design

This experiment aims to compare the data retrieved from the gyroscope in the mobile phone against measured angles to determine the potential for error in the angles of elevation and depression.

Implementation

Most mobile phones (including the Apple iPhone family) incorporate a gyroscope which can be used to determine the position of the device.[208]Data from this could assist us to determine the angle of elevation and angle of depression. The axis of the iPhone is shown in Figure 17 where the pitch of the mobile phone could correspond to the angle of elevation or depression.

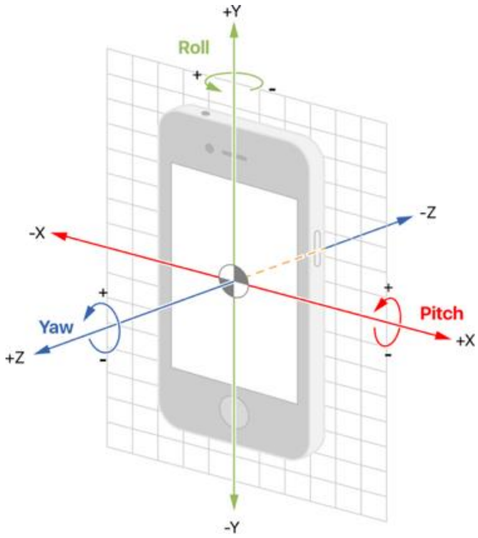


Figure 17 - Pitch and yaw of phone[209]

With known angles, missing distances may be able to be calculated.[210] For example, taking one photograph of the child's feet and then one of their head could allow the use of the pitch of the phone to determine the angle of depression or elevation. The angles could then assist in the calculation of the height of the child. In doing this, the camera would need to be in a fixed position or the distance to the floor must be known for both photographs. Another option that could be investigated in future research is the utilisation of the accelerometer to determine the movement of the phone and in turn, this could indicate the position of the mobile phone in space.

Firstly, the accuracy of the gyroscope in the iPhone 7 was tested by measuring the pitch of the smartphone manually and matching this with gyroscope data at 10-degree increments. Each gyroscope measurement and the actual angle was measured (using a protractor) three times, and the median of the three recorded as the included measurement.

At this time, *MATLAB*[211] mobile did not allow image capture and gyroscope measurements on the iPhone without being tethered to a laptop by a cable which made image and pitch data acquisition challenging to obtain. However, *Xcode*[212] has a stable image data acquisition, and Swift programming language can be used to acquire the image and return a measurement of pitch data (Code Snippet 1).

Code Snippet 1 - Obtaining gyroscope data for testing

```
// ViewController.swift
// WEWW App
// Created by Sally Britnell on 19/03/17.
// Copyright © 2017 Sally Britnell. All rights reserved.

import UIKit
import AVFoundation
import CoreMotion

class ViewController: UIViewController,AVCapturePhotoCaptureDelegate {
  @IBOutlet var cameraDisplay: UIView!
  @IBOutlet var takePhoto: UIButton!
  @IBOutlet var GyroLabel: UILabel!
  @IBOutlet var gyroData: UILabel!

  var captureSession : AVCaptureSession!
  var cameraOutput : AVCapturePhotoOutput!
  var previewLayer : AVCaptureVideoPreviewLayer!
  var motionManager = CMMotionManager()
  var gyroPitch = 0.0

  override func viewDidLoad() {

    if motionManager.isAccelerometerAvailable {
      motionManager.deviceMotionUpdateInterval = 0.2;
      motionManager.gyroUpdateInterval = 0.01
      motionManager.startDeviceMotionUpdates()

      motionManager.startAccelerometerUpdates(to: OperationQueue.current!)
      { (data , error) in self.view.reloadInputViews()
        let attitude = self.motionManager.deviceMotion!.attitude
        let gyroPitch = attitude.pitch * (180.0 / M_PI)
        self.gyroData.text = "\(gyroPitch)"
      }
    }
  }
```

Testing

The following steps are the procedure for this experiment.

1. Using a tripod: ensure the tripod is stable and level on the floor.
2. Attach protractor to the tripod and ensure this is firmly taped to bend at the point the tripod pitch alters (Figure 18).
3. Place the phone in the case on the tripod and set to a 90-degree position.
4. Check the 90-degree position three times.
5. Take a photograph, screenshot the gyroscope data (pitch, roll and yaw) three times in succession checking that the 90-degree angle is maintained.
6. Repeat steps 4-6 for each 10-degree increment.

Figure 18 - Tripod setup to measure angle of photograph from the base of the tripod

Results of this experiment are shown in Table 15.

Table 15 - Comparing the gyroscope (pitch) with the angle of camera based on the tripod tilt

Measured Length (cm)	Angle	Gyroscope Pitch 1	Pitch 2	Pitch 3	Average ≈ Pitch	Error Pitch
65	-90	-88.86	-88.74	-87.53	-88.38	-1.62
65	-80	-79.55	-79.15	-79.07	-79.26	-0.74
65	-70	-69.1	-68.83	-69.32	-69.09	-0.91
65	-60	-58.74	-58.75	-58.36	-58.62	-1.38
65	-50	-48.24	-48.23	-48.02	-48.16	-1.84
65	-40	-35.45	-35.9	-35.78	-35.71	-4.29
65	-30	-27.57	-27.74	-27.95	-27.75	-2.25
65	-20	-17.88	-17.77	-17.98	-17.88	-2.12
65	-10	-10.49	-11.35	-10.65	-10.83	-0.83
				Average Error		-1.59

While this experiment only showed a minimal error of -1.59 degrees, I made an error in the setup of this experiment. The angle (pitch) measurement was from the bend in the tripod rather than the centre of the phone where the gyroscope is located. Therefore, with these errors corrected, the experiment was repeated with the results shown in Table 16.

Table 16 - Testing the gyroscope in the iPhone 7 with measurement of angle at the centre of the phone

Measured Length (cm)	Angle	Pitch 1	Gyroscope Pitch 2	Pitch 3	Average ≈ Pitch	Error Pitch
65	-90	-88.89	-88.94	-89	-88.94	-1.06
65	-80	-78.33	-78.37	-78.36	-78.36	-1.64
65	-70	-68.44	-68.51	-68.56	-68.51	-1.49
65	-60	-59.37	-59.41	-59.43	-59.41	-0.59
65	-50	-49.89	-49.92	-50.04	-49.92	-0.08
65	-40	-38.9	-38.88	-38.89	-38.89	-1.11
65	-30	-30.21	-30.29	-30.33	-30.29	0.29
65	-20	-19.84	-19.87	-19.88	-19.87	-0.13
65	-10	-10.14	-10.13	-10.15	-10.14	0.14
					Average Error	-0.63

Evaluation

The first set of results illustrate the accuracy of the gyroscope of an iPhone 7, which had an average of -1.59 degrees of error on testing. On repetition of the experiment using the centre of the iPhone as the pivot point, the average error was -0.63 degrees.

Determining the acceptable level of error in pitch was not possible, as this is novel research. Literature discussing the accuracy of pitch is not available. This experiment shows that using the gyroscope of the iPhone 7 could be acceptable to determine the angle of elevation or depression. However, testing would need to be performed to determine the accuracy of sensor data and the impact this has on medication doses or equipment sizes in resuscitation for each model of mobile phone.

5.3.2 Angles of elevation and depression to determine the height of a child

Design

This experiment aims to use trigonometry to calculate the angle of depression and angle of elevation,[210] to assist in the application of photogrammetry to measure the child in Figure 19.

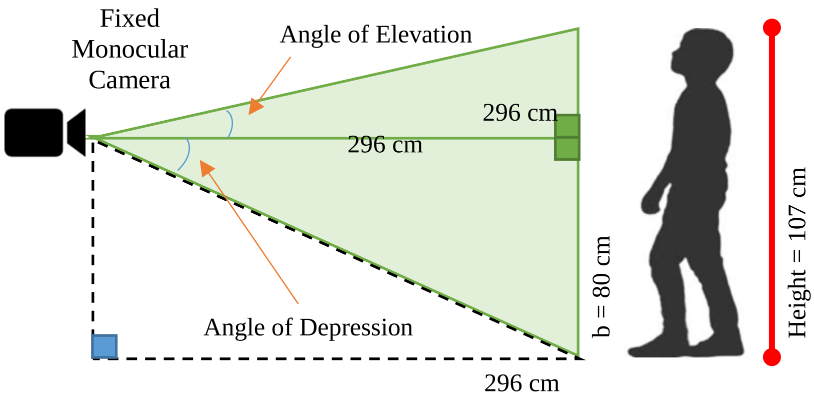


Figure 19 - Height can be used to determine angles of elevation and depression

Implementation

Angle of elevation and depression can be calculated using Equation 7.

Equation 7 – calculation of the height of a child in a photograph using angles of elevation and depression$height = (\tan \angle\, angle\ of\ depression\ \times\ distance\ to\ child) +$

$$height = (\tan \angle\, angle\ of\ depression\ \times\ distance\ to\ child) + (\tan \angle\, angle\ of\ elevation\ \times\ distance\ to\ child)$$

Testing

Equation 8 – the application of Equation 7 to data from Figure 19

$$height = (tan\emptyset\, T3\ B\ \times\ T3\ a) + (tan\emptyset\ \ T2\ B\ \times\ T2\ a)$$

$$height = \left(tan\emptyset\left(tan\emptyset^{-1}\left(\frac{T3b}{T3a}\right)\right) \times T3a\right) + \left(tan\emptyset\left(tan\emptyset^{-1}\left(\frac{T2b}{T2a}\right)\right) \times T2a\right)$$

$$height = \left(tan\emptyset\left(tan\emptyset^{-1}\frac{27}{296}\right) \times 296\right) + \left(tan\emptyset\left(tan\emptyset^{-1}\frac{80}{296}\right) \times 296\right)$$

$$height = 107\ cm$$

Evaluation

The utilisation of angles of elevation and depression for this experiment matched the measurements of both angles and distance to the child. Therefore, the angle of elevation and depression could assist in determining the height of a child.[210] As with earlier experiments, this relies on known measurements, such as the distance from the camera to the child.

As the WEWW application will be deployed in a variable environment, the distance to the child and measurement from the floor to camera/angle of elevation or depression are not fixed and may not be known. Without these values, the angle of elevation and depression cannot be used in subsequent calculations and an alternative source of this information is required.

5.4 Detection of an object in a photograph

The human brain interprets information from all senses[213] and it is continually actively sensing the world. For some, this information may be of assistance in a stressful and complicated situation, however, for others, it may add complexity, increasing cognitive load and decision density.[7] Implementing photogrammetry during resuscitation could potentially minimise cognitive load through automatic object detection and measurement (namely, of a child), and could ensure consistent measurements/weight estimates during resuscitation.

Analysis of a person in a photograph requires first the detection of the person in the photograph, followed by measurement. A human brain can easily distinguish a particular object in a photograph but automating this process by using computer vision on a mobile device to detect or recognise an object is complex albeit achievable. While mobile phone applications for matching objects already exist,[214] performing image analysis is more complex and time-consuming. One example of this process being used in medicine is to measure and classify diabetic foot ulcers by image analysis performed on a smartphone[215] which adds consistency to measurements. However, even with down-sampling the initial image the processing time was 15 seconds of image analysis[215] which could increase time to treatment in an emergency situation. Resuscitation is time critical where increasing time to treatment decreases the chance of survival[102, 103, 149, 216-218] What this means is reducing the image processing time needs to be an essential consideration in the design of the WEWW application.

The following experiments have been designed to test the ability of computer vision tools to detect a person in a photograph using an artefact similar to the checkerboard in Figure 20.

Figure 20 - Objects to measure using a checkerboard artefact

5.4.1 Detection of objects in a photograph using grey thresholding

Thresholding is the process of using filters to convert the entire image to a binary (black and white) format, where regions of the photograph can be analysed based on pixel colour.[219]

Design

This experiment will apply grey thresholding to the image shown in Figure 20 to produce a binary image of detected objects.

Implementation

The first step in this process is to convert the image to Hue, Saturation, Value (HSV) format and return the saturation channel. The saturation value is used to calculate the grey threshold (Code Snippet 2).

Code Snippet 2 - Thresholding an image using *MATLAB*

```
% Convert the image to the HSV colour space.
imHSV = rgb2hsv(image);

% Get the saturation channel.
saturation = imHSV(:, :, 2);

% Threshold the image
t = graythresh(saturation);
segmented = (saturation > t);

% Display the original and segmented image
subplot(1,2,1), imshow(image)
title('Original Image');
subplot(1,2,2), imshow(segmented)
title('Segmentation using Thresholding');
```

After the above segmentation of the image, detecting objects is required. Code Snippet 3 is then used to return the two largest objects that are not the checkerboard artefact in the photograph. In this case the glasses case and the tape measure.

Code Snippet 3 - Detect and display the two largest objects in a photograph

```
  % Find the connected components returning these in an array
  blobAnalysis = vision.BlobAnalysis('AreaOutputPort', true,...
    'CentroidOutputPort', false,...
    'BoundingBoxOutputPort', true,...
    'MinimumBlobArea', 200, 'ExcludeBorderBlobs', true);
  [areas, boxes] = step(blobAnalysis, imCoin);

  % Sort connected components in descending order by area
  [~, idx] = sort(areas, 'Descend');

  % Return the two largest objects and set the scale to 17%.
  boxes = double(boxes(idx(1:2), :));
  scale = 0.17;

  % Scale the photograph for the display
  imDetectedObjects = imresize(image, scale);

  % Label the objects that were found
  imDetectedObjects = insertObjectAnnotation(imDetectedObjects, 'rectangle',
...
    scale * boxes, 'object');
  figure; imshow(imDetectedObjects);
  title('Detected Objects');
```

This experiment will be run using two photographs, one with consistent coloured objects and background and the other with multi-coloured objects and background.

Testing

Figure 21 shows the output of the first run of this experiment with the code to perform this shown in (Code Snippet 2). Figure 22 is showing the objects detected using grey thresholding technique in Code Snippet 3.

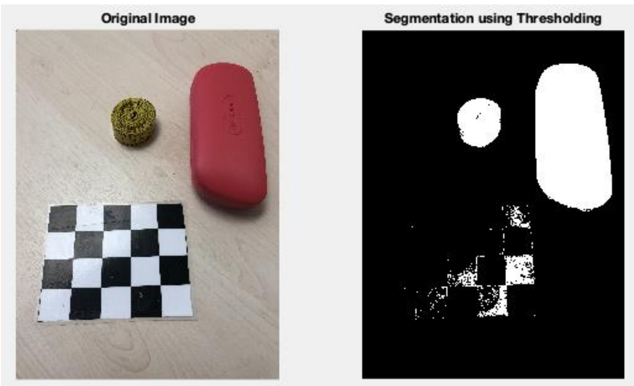


Figure 21 – Grey thresholding to detect objects in a photograph

Figure 22 - Detected objects using a grey thresholding process

Figure 23 illustrates the same process using a photograph with a textured background and inconsistently coloured objects.

Figure 23 - Detected textured object using the grey threshold process

Evaluation

This experiment was successful at finding the required objects, the glasses case and tape measure in Figure 22, however, this appears to be primarily due to the consistent colour of objects to be detected, especially when on a uniform background. Repeating the same experiment under different conditions with different objects was not as successful (Figure 23). Objects were either not detected or only partially detected illustrating the effect that the environment and the object itself has on the ability of the algorithm to detect photograph contents.

Overall, the grey thresholding process will easily allow detection of consistently coloured objects on a uniform background. However, during resuscitation, a child will not always be consistently coloured or textured against a uniform background. Therefore, utilising grey thresholding is not optimal for detection of a child during resuscitation due to the unpredictable environment.

5.4.2 Detection of a child in a photograph using colour thresholding

Design

An alternative to grey thresholding for detecting objects in a photograph is colour thresholding which can allow the detection of consistent colours in a photograph. When working with humans, this could be the skin colour.

Implementation

Firstly, this experiment will test the process of colour thresholding by converting an image to binary through the removal of colour channels. Removing colour channels allows the detection of specified colours along with the removal of the checkerboard artefact and background as shown in

Code Snippet 4.

Code Snippet 4 – *MATLAB* code for colour thresholding to assist with object detection

```
% Import an image to detect skin colour and determine its size
   oringinalImage = importImage();
   height = size(oringinalImage,1);
   width = size(oringinalImage,2);

   % Create a blank output image mask using the height and width above
   outputImage = oringinalImage;
   binaryImage = zeros(height,width);

   % Apply Grayworld Algorithm for illumination compensation
   image = grayworld(oringinalImage);

   % Convert the image from RGB to YCbCr colour space
   ycbcrColourSpaceImage = rgb2ycbcr(image);
   Cb = ycbcrColourSpaceImage(:,:,2);
   Cr = ycbcrColourSpaceImage(:,:,3);

   % Detect skin in photograph
   [r,c,v] = find(Cb>=77 & Cb<=127 & Cr>=133 & Cr<=173);
   numind = size(r,1);

   % Mark skin coloured pixels as blue
   for i=1:numind
     outputImage(r(i),c(i),:) = [0 0 255];
     binaryImage(r(i),c(i)) = 1;
   end

   % Plot the images in a montage
   subplot(1,3,1), imshow(oringinalImage)
    title('Original Image');
   subplot(1,3,2), imshow(outputImage)
    title('Detected skin in blue');
   subplot(1,3,3), imshow(binaryImage);
    title('Binary Image');
```

Testing

This code was tested using two photographs (Figure 24): one staged photograph with skin showing for the sake of this experiment and one of a child laying down in the grass (freely available on the internet)[220] with less skin colour showing to illustrate colour thresholding.

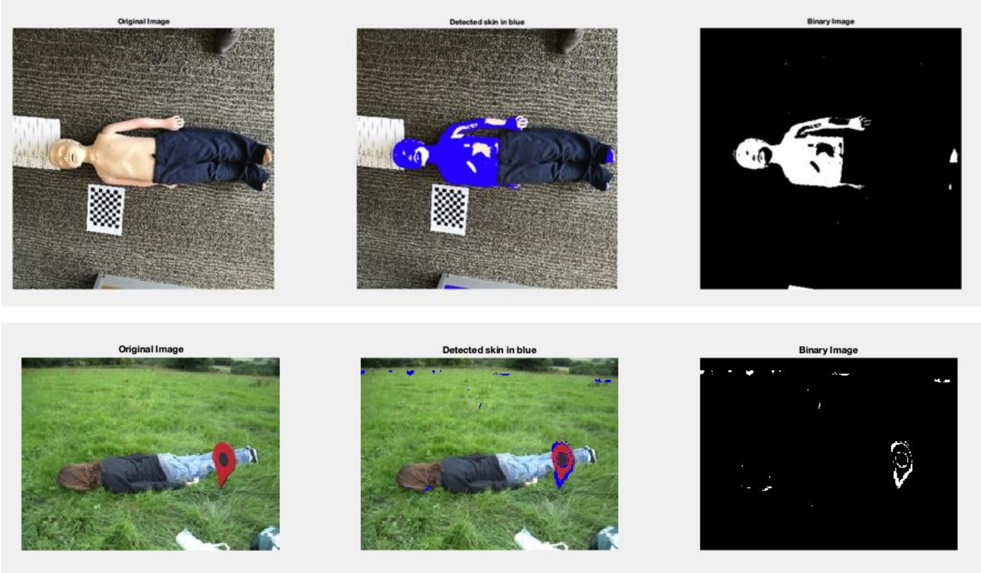


Figure 24 - Colour thresholding to detect skin in a staged photograph and one where less skin is showing[220]

Evaluation

Colour thresholding to detect the skin is useful if much skin is showing against a contrasting background, for example, when a child is naked and on a dark background. This experiment tested skin detection using a mannequin with a bare chest (the first set of photographs) compared with a child in an outdoor environment similar to a sports field where less skin was showing (the second set of photographs in Figure 24). However, the removal of clothing may not be appropriate in all resuscitation situations. Clinical staff are rarely able to control the presenting situation in a paediatric resuscitation, and the time taken to undress the child in order to take a photograph and then go on to estimate weight could increase the time to treatment. Therefore, this method of object detection will not consistently work in all situations and is not appropriate for the needs of the WEWW application.

5.4.3 Detecting a child in a photograph using edge detection algorithms

Design

Detecting the edge of a person for measurement is an essential step in being able to analyse the child to be measured in the photograph. While many algorithms for edge detection exist in computer vision, all perform slightly differently depending on the image being analysed.[221, 222] *MATLAB* offers several forms of edge detection 'Sobel' (default), 'Prewitt', 'Roberts', 'log', 'zerocross', 'Canny', 'approxcanny' and provides a table summarising these (Table 17).

Table 17 - Edge detection methods included in *MATLAB* software

Method	**Description**
'Sobel'	Finds edges at those points where the gradient of the image I is maximum, using the Sobel approximation to the derivative.

Method	Description
'Prewitt'	Finds edges at those points where the gradient of I is maximum, using the Prewitt approximation to the derivative.
'Roberts'	Finds edges at those points where the gradient of I is maximum, using the Roberts approximation to the derivative.
'log'	Finds edges by looking for zero-crossings after filtering I with a Laplacian of Gaussian (LoG) filter.
'zerocross'	Finds edges by looking for zero-crossings after filtering I with a filter that you specify
'Canny'	Finds edges by looking for local maxima of the gradient of I. The edge function calculates the gradient using the derivative of a Gaussian filter.
'approxcanny'	Finds edges using an approximate version of the Canny edge detection algorithm that provides faster execution time at the expense of less precise detection. For the approxcanny method, floating point images are expected to be normalized in the range [0 1].

The Canny method of edge detection is generally the most reliable in 'noisy' photographs. The point of difference in the Canny algorithm (see Table 17) was the use of a Gaussian method to smooth edges for detection.[221, 222] The following experiment will test all available methods of edge detection in the *MATLAB* software on analysis of a photograph with the knowledge that the Canny method is considered the most reliable.

Implementation

Utilise edge detection methods in *MATLAB* to detect an object of interest. Apply the different methods of edge detection to a coloured photograph (converted to black and white) to detect the edge of a person using *MATLAB* (Code Snippet 5).

Code Snippet 5 - Use the 'Canny' edge detection method to detect a person in a photograph

```
%Detect the edges of the photograph using different filters
function [ edges ] = detectEdges( image )
  BW = rgb2gray(image);
  BW1 = edge(BW,'sobel');
  BW2 = edge(BW,'prewitt');
  BW3 = edge(BW,'roberts');
  BW4 = edge(BW,'log');
  BW5 = edge(BW,'zerocross');
  BW6 = edge(BW,'canny');
  subplot(3,3,2), imshow(image),title('Original Image');
  subplot(3,3,3), imshow(BW),title('Original Image BW');
  subplot(3,3,4), imshow(BW1),title('Sobel');
  subplot(3,3,5), imshow(BW2),title('Prewitt');
  subplot(3,3,6), imshow(BW3),title('Roberts');
  subplot(3,3,7), imshow(BW4),title('Log');
  subplot(3,3,8), imshow(BW5),title('Zerocross');
  subplot(3,3,9), imshow(BW6),title('Canny');
 end
```

Testing

Edge detection was applied using the above code with the default settings (Figure 25) to determine the ability of edge detection algorithms to detect a person in a busy photograph downloaded from the internet.[220]

Figure 25 – Photographs with common edge detection algorithms applied

Evaluation

This photograph represents an unconscious child on a sports field, a typical situation where weight estimation is required so that the correct dose of medication can be given before moving the patient (Figure 25).

All of the methods of edge detection tested above were unable to differentiate the child from the background automatically. While edge detection could be possible by utilising the colour of the grass, that would mean that the user would need to specify this colour. The WEWW application needs to function in multiple environments with minimal user interaction in life-threatening situations, therefore, the accuracy and speed of edge detection are paramount. With this in mind, edge detection needs to provide precise and timely results. Therefore, alternative methods of detecting the child in a photograph were sought and tested.

5.4.4 Detection of people in a photograph

Design

MATLAB documentation revealed an existing class called *detectPeople*. Therefore, this experiment will utilise the *detectPeople* class in *MATLAB* to detect a person in a photograph.

Implementation

MATLAB has functionality to detect people and match objects in photographs which is shown in Code Snippet 6.

Code Snippet 6 - *MATLAB* built-in function to detect people in a photograph

```
function [ people ] = detectPeople( I )
peopleDetector = vision.PeopleDetector;
[bboxes,scores] = step(peopleDetector,I);
people = insertObjectAnnotation(I,'rectangle',bboxes,scores);
figure, imshow(people); title('Detected people and detection scores');
disp('end people detected');
end
```

Testing

On analysis an image[220] of a child laying (Figure 26) or standing (that is, when the image was rotated 90°) showed no people detected.

Figure 26 - Photograph of child laying down[220] tested with the people detection class

On analysis of a further public domain image[223] a person was detected; however, other people in the photograph were not detected. Furthermore, the results were inconsistent with bounding boxes were considerably larger than the people and one bounding box (labelled 0.051605 in Figure 27) only detecting the lower half a person's body within a larger bounding box containing a whole person. Therefore, the *detectPeople* function was unable to determine an individual person in the photograph and will not be considered a reliable option to include in the development of the WEWW application.

Figure 27 - Bounding boxes using *peopleDetect* algorithm in *MATLAB*[211, 223]

The inconsistency of people detection and the inaccuracy of bounding boxes could in turn cause error in the measurement of objects within a photograph, therefore the built-in *peopleDetect* algorithm in *MATLAB* is not appropriate for use in this application.

Evaluation

As illustrated above in Figure 26 and Figure 27, object detection of people in photographs remains inconsistent when using the built-in *MATLAB* function called *peopleDetect*. As speed and accuracy are paramount during resuscitation the existing *peopleDetect* class will not be appropriate for detection of a child. Therefore an alternative method of detecting the child is required for development of the WEWW application.

5.4.5 Foreground and background detection

Design

On consultation with Dr Boris Bačić,[224] a Senior Lecturer at Auckland University of Technology who has research interests in video and image detection, using video foreground and background segmentation to detect the silhouette of a person for measurement was suggested. This silhouette could signify the edge of the person to be measured.

Implementation

Investigation of segmentation of video revealed the following existing algorithm[225] which was adapted to become the code shown in Code Snippet 7. This code separates the background and foreground of a video to produce a silhouette of the moving portion of the video as shown in Figure 28.

Code Snippet 7 - Separated the foreground from the background using video

```
%% read the video
reader = VideoReader('Person walking.mp4');
vid = (Healthcare, 2018);
while hasFrame(reader)
  vid{end+1} = im2single(readFrame(reader));
end

%% simple background estimation using mean
bg = mean( cat(4, vid[226]), 4 );

%% estimate foreground as deviation from the background
fIdx = 43; % do it for frame 43
fg = sum( abs( vid{fIdx} - bg ), 3 ) > 0.25;

figure;
subplot(131); imshow( bg );
subplot(132); imshow( vid{fIdx} );
subplot(133); imshow( fg );
```

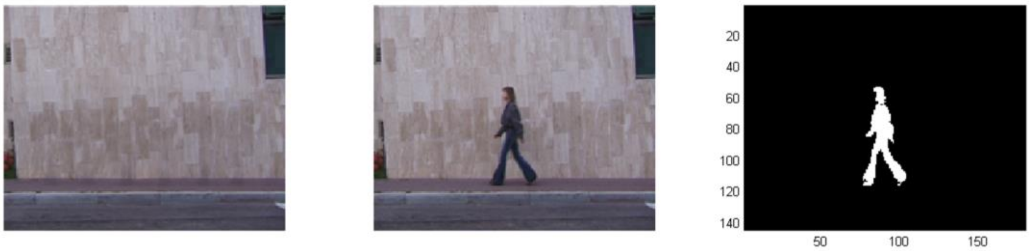


Figure 28 - Example (code above) applied to a video from the MATLAB documentation[225]

Testing

One pitfall of this method was that both the camera and background of the image needed to be static. Therefore, when the same code was applied to a video of a person walking[227] while the camera position also moved, this algorithm was unable to successfully detect the foreground from the background as camera and subject were moving (Figure 29).

Figure 29 - Above code applied to a video from YouTube[227]

A still photograph (Figure 30) was the output of Code Snippet 8 which tested the segmentation of the foreground and background of a movie. Unfortunately, processing time was > 5 seconds as the movie needed to be buffered the first time it was used. Therefore, a different type of video processing (snapshot of frames) using the same MacBook Pro with 16 GB ram and 2.3 G processor was attempted and resulted in the same processing time. With time to treatment and CPU load in mind, porting or transferring this process to a mobile device could potentially increase the processing time further.

Code Snippet 8 - Application of edge detection using video frames

```
%% create the video object and step through frames applying the canny mask
  try
    vid = imaq.VideoDevice('macvideo',1);
    set(vid,'ReturnedColorSpace','grayscale');
    framesToCapture = 100;
    figure;
    set(gcf,'doublebuffer','on');
    frameCount = 0;

    while (frameCount <= framesToCapture)
      I = step(vid);
      i = edge(I,'canny',.3);
      figure(1); imshowpair(I, i, 'montage')
      frameCount = frameCount + 1;
    end
    release(vid);
    delete(vid);
    clear vid;
```

Figure 30 - Edge detection using foreground/background segmentation of original video capture using the canny feature

Evaluation

A downfall of using segmentation of foreground and background in a video for edge detection is that it uses a lot of Central Processing Unit (CPU) power yet the advantage is that there are many frames of content to compare. While comparison of video frames can indeed produce segmentation of foreground and background, this takes CPU power and time to process which could in turn impact on the survival of a patient in a resuscitation. Furthermore, segmentation in this manner requires the movement of the patient against a static background. During resuscitation, most children have a decreased level of consciousness and are therefore not moving much, making segmentation of foreground and background to detect a child a non-viable option. Thus, an alternative method of edge detection is required.

5.4.6 User input to identify an object in a photograph

To move on with this research, analysis and tweaking of object detection algorithms was discontinued and user input was implemented to identify the object to be measured in each photograph. While user input to identify a child in the photograph removes some of the barriers identified in detecting the child, this user interaction could introduce further error and cognitive load which will be addressed during testing of the WEWW application as well as in future research.

Keeping simplicity and minimal user input in mind, the least information required to estimate the weight is the length of the child in a photograph. The user can indicate this by tapping the screen at the top of the head and the bottom of the heel of the child.

Design

This experiment aimed to get user input to specify the length of an object in a photograph using *MATLAB.* In this case, mouse clicks will simulate user taps on a mobile device screen. User input on the mobile device will be addressed during functional and user testing of the WEWW application.

Implementation

The decision was made not to further develop code to detect the object in the photograph; instead, user input will specify the size of the object in the photograph using functions such as *getLine* or *input* classes in *MATLAB.* Detection of people using other methods will now occur as a post-doctoral component of this project.

Testing

Once camera calibration was completed, the class in Code Snippet 9 was used to generate a line based on where the user clicked on the screen and the length of the line in pixels was calculated to later be converted to a measurement in cm.

Code Snippet 9 - User input to detect object size

```
%% get user input to specify a line and measure this line
function [line,length, position] = getLine(~)
[x,y] = ginput(2);
hold on
line = imdistline(gca,x,y);
api = iptgetapi(line);
length = api.getDistance();
position = api.getPosition();
hold off
end
```

Evaluation

This project aims to increase the accuracy of weight estimation and in the process potentially decrease the cognitive load. Having the user specify the dimensions of the child by tapping on the head and feet could alter the cognitive load but could also alter the accuracy of weight estimation. However, it decreases the processing time and CPU usage. For the prototype developed in this PhD, user input will be used to specify the dimensions of the object with the knowledge that object detection can be revisited in future research.

5.5 Measurement from a photograph

5.5.1 Camera calibration

Several papers have investigated the measurement of objects such as trees or humans without an artefact.[228-231] These often assumed that the camera was parallel to the object for measurement. If the person or object to be measured is not parallel to the camera, the height of the camera, rotation, and pitch of the object for measurement need to be translated from the real-world which is three-dimensional (3D) to the digital world which is two-dimensional (2D).[229-231] As discussed earlier, ensuring a parallel photograph may not be possible in the variable and busy resuscitation environment, so the photograph needs to be corrected for analysis during the camera calibration process.

Design

This experiment aimed to use an artefact (of known dimensions) on the same planar surface in a photograph to calibrate the camera and remove any distortion.

1. Utilise an artefact to calibrate the camera.

2. Create an image set for optimal camera calibration.
3. Remove distortion in image set.

When the depth of field or camera angle distorts a photograph, the range or distance to the object being measured can be corrected using camera calibration. Using a chequerboard pattern as an artefact provides known uniform dimensions[232] that can be utilised to measure depth within a photograph. The use of a black and white checkerboard pattern of a known size is well established in photogrammetry, as the black and white checks allow for sharp contrast and allow for ease in the detection of corners.[232]

Learning about the camera position in space is often called camera calibration, which is the process where an algorithm determines the relationship between the position of an object in the image and the position of the same object in real life.[232] This is usually expressed using a coordinate system, which allows manipulation of the characteristics of the camera and differences in scale required to interact with the environment in the photograph.[233]

Table 18 shows examples of camera calibration methods. Camera calibration is generally determined by using a perspective geometrical model and refined by bundle adjustments.[234] These authors suggest using an automated self-calibration adjustment bundle where possible, however, they acknowledge that this is often not possible in close range photogrammetry such as this project.[234] Another author suggests that the process of camera calibration involves: processing several images containing the same planar calibration pattern, extracting the internal corners of the pattern from the image, then matching the corresponding 2D image points with the 3D image points. The relationship between the 2D and 3D points allows calculation of the intrinsic and extrinsic properties of the camera from points in the photograph.[232] The number of images required for camera calibration varies between authors. For example, one suggests "several" images,[232] while others recommend analysis of between 10 - 20 images to ensure an accurate method of determining the adjustments between the real-world (3D) and camera (2D) positions.[235]

Table 18 - Differences between camera calibration methods.

	Tsai (1987)[236]	**Heikkila & Silven (1997)[237]**	**Zhang (2000)[238]**
Camera	Pinhole	-	
Parameters	Some provided by manufacturer	Estimates then closed-form solution (DLT)	
Model	Linear equation	nonlinear least-squares estimation	Corner point extraction, then projective transformation then Intrinsic and extrinsic properties returned
Distortion Model	Distortion Model	Levenberg-Marquardt algorithm	linear least-squares solution Levenberg-Marquardt method

Points	8+	-	
Images	Single or Multiple	Single or Multiple	
Artefact	Grid points must be known		Planar checkerboard grid at multiple angles
Problems		-	

The use of *MATLAB* as rapid prototyping software is well established in the computer vision literature.[239-242] The *MATLAB* software provides existing libraries for camera calibration and manipulation of data stored in the photographs used during object detection.[235]

Implementation

During camera calibration, a set of photographs was analysed. Checkerboard artefacts were detected in each photograph where a set of coordinates (*imagePoints)* for each of the internal corner points of each square was detected. These coordinates allowed for removal of distortion and translation in the real-world coordinates (*worldPoints)* for later use.

For this experiment 20 photographs were taken at random angles with no zoom using an iPhone 7 (Figure 31) and then imported into *MATLAB* (Code Snippet 10).

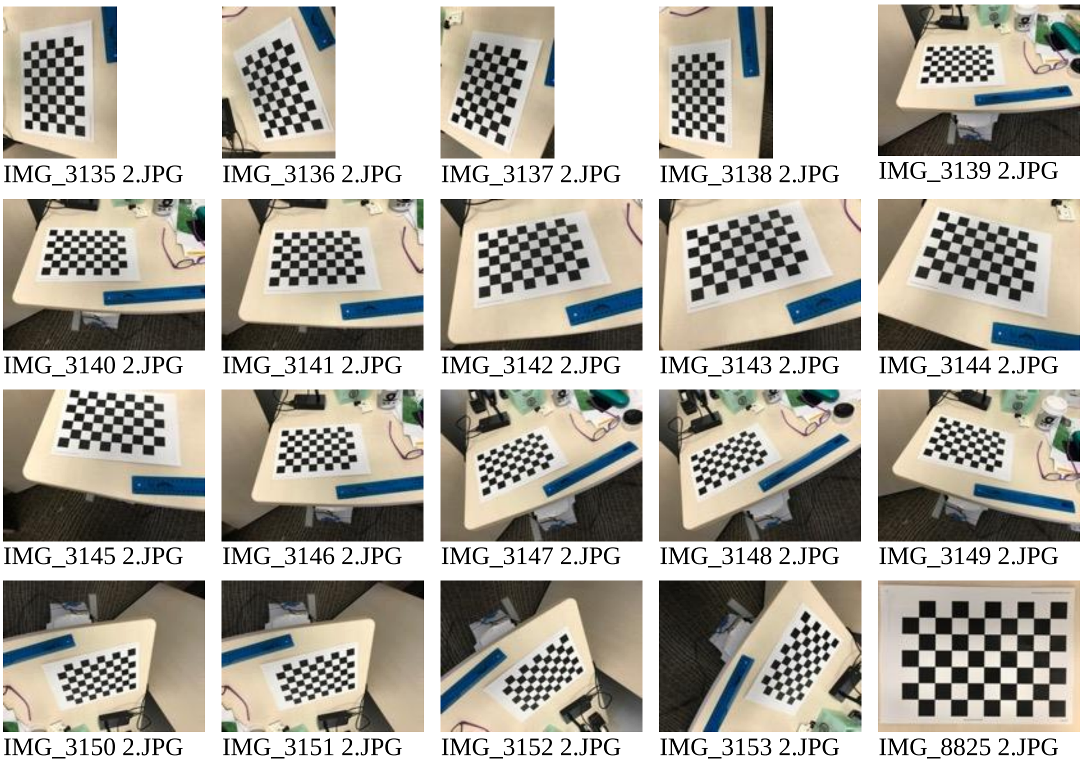


Figure 31 - Images used to calibrate a camera that contain the same checkerboard pattern.

Code Snippet 10: Import photographs to *MATLAB*

```
   % State which files are to be examined
   imageFileNames = {'IMG_3153.JPG’, IMG_3151.JPG', 'IMG_3152.JPG',
   'IMG_3150.JPG', 'IMG_3149.JPG', ‘IMG_3148.JPG', ‘IMG_3146.JPG',
‘IMG_3144.JPG', ‘IMG_3145.JPG', ‘IMG_3143.JPG', ‘IMG_3142.JPG',
‘IMG_3140.JPG', ‘IMG_3141.JPG', ‘IMG_3139.JPG', ‘IMG_3138.JPG',
‘IMG_3137.JPG', ‘IMG_3136.JPG', ‘IMG_3135.JPG', IMG_8825.JPG'};

   % Detect checkerboards in all of the images detect all corners
   [imagePoints, boardSize, imagesUsed] =
detectCheckerboardPoints(imageFileNames);
   imageFileNames = imageFileNames(imagesUsed);
```

Code Snippet 11 creates a set of checkerboard coordinates representing a 3D checkerboard that correlates to the 2D checkerboard in the photograph. The 3D checkerboard is then resized to match the *squareSize* (23mm) to allow for measurement in the photograph.

Code Snippet 11 – Detect the checkerboard and generate *worldPoints*

```
   % Detect the checkerboard in the first photograph and determine the number
or rows and columns
   originalImage = imread(imageFileNames);
   [mrows, ncols, ~] = size(originalImage);

   % Generate the coordinates of the corners of a 23mm height and width square
   squareSize = 23; % in units of 'millimeters'
   worldPoints = generateCheckerboardPoints(boardSize, squareSize);
```

Many calculations to obtain the measurement in photogrammetry use distance from the camera to an object and then calculate the real-world measurements.[243] Similarly, *MATLAB* calculates the *cameraParameters* which represent the difference between the *imagePoints* (2D coordinates from the photograph) and *worldPoints* (calculated 3D coordinates) and estimates errors to remove any distortion (Code Snippet 12).

Code Snippet 12 - Determine camera parameters and remove any distortion caused by the camera lens

```
  % Calibrate the camera
  [cameraParams, imagesUsed, estimationErrors] =
estimateCameraParameters(imagePoints, worldPoints, ...
     'EstimateSkew', false, 'EstimateTangentialDistortion', false, ...
     'NumRadialDistortionCoefficients', 2, 'WorldUnits', 'millimeters', ...
     'InitialIntrinsicMatrix', [], 'InitialRadialDistortion', [], ...
     'ImageSize', [mrows, ncols]);
   % Use the calibration data to remove lens distortion
  [image, undistortedImage] = undistortImage(originalImage, cameraParams);
```

On import of photographs the *cameraCalibration* application within the *MATLAB* software, three photographs were rejected (Figure 32) with no rationale for rejection given by the software. The rejected photographs were removed from the camera calibration process.

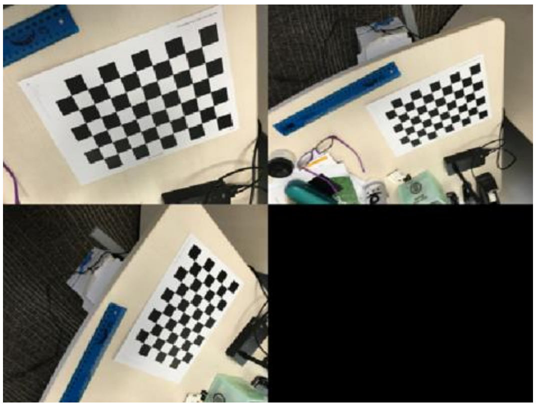


Figure 32 - Photographs rejected by the built in *MATLAB* camera calibration application

On analysis of the remaining 17 photographs, a checkerboard model showing points where squares intersected was created for each image (for example, see Figure 33). Coordinates of these points are stored in an array called *worldPoints*. The difference between the *imagePoints* and *worldPoints* can be used to determine the rotation and tilt that needs to be applied to the photograph to align the chequerboard for later measurement of objects. These points are used by the camera calibration application within the *MATLAB* software to calculate the mean error in each photograph for further analysis.

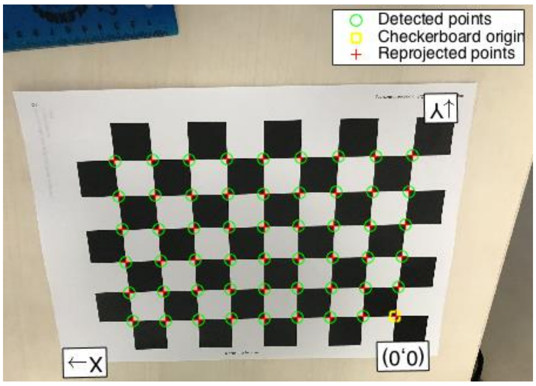


Figure 33 - points detected on checkerboard by *MATLAB cameraCalibrator*

Testing and Evaluation

An acceptable error level for reprojection errors in measurement (mm or pixels) was not evident in a literature search. However, multiple sources agree that minimising reprojection error during camera calibration provides more accurate measurements when using computer vision.[235, 244, 245] The following reprojection errors were present and showed a mean error of 1.08 pixels across all images (Figure 34). These images produced the *Extrinsic* properties shown in Figure 35.

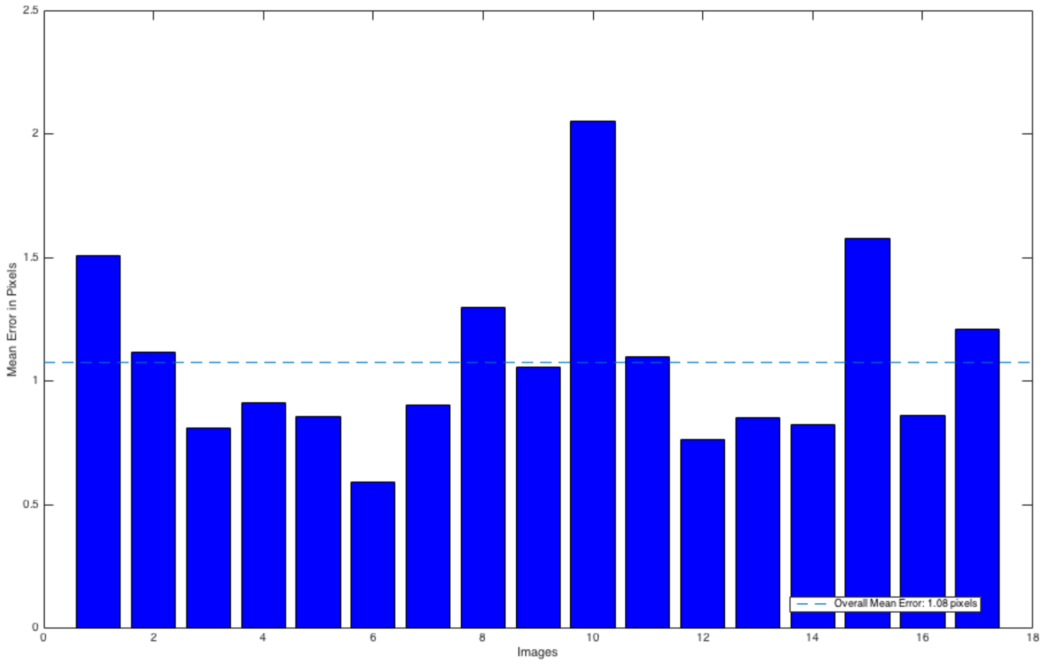


Figure 34 - Error found on camera calibration using 17 the images that were not rejected

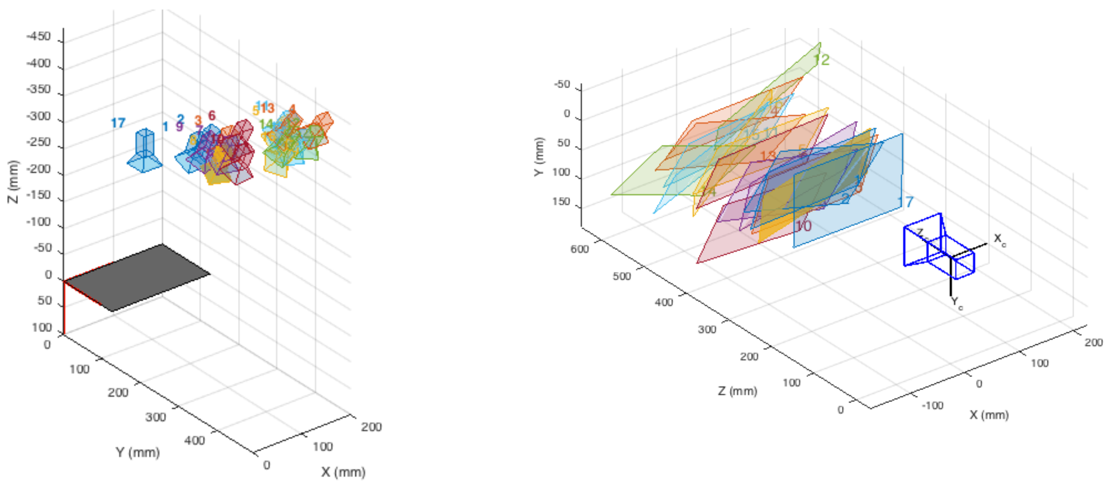


Figure 35 – Extrinsic data from the camera calibration for images that were not rejected

To reduce the effect reprojection errors have on camera calibration, two images that had a mean reprojection error of > 1.5 pixels were removed and camera calibration was re-run without these two photographs (Figure 36). Removal and recalculation led to a lower mean error of 0.96 pixels. These camera parameters were accepted and have been utilised for future experiments.

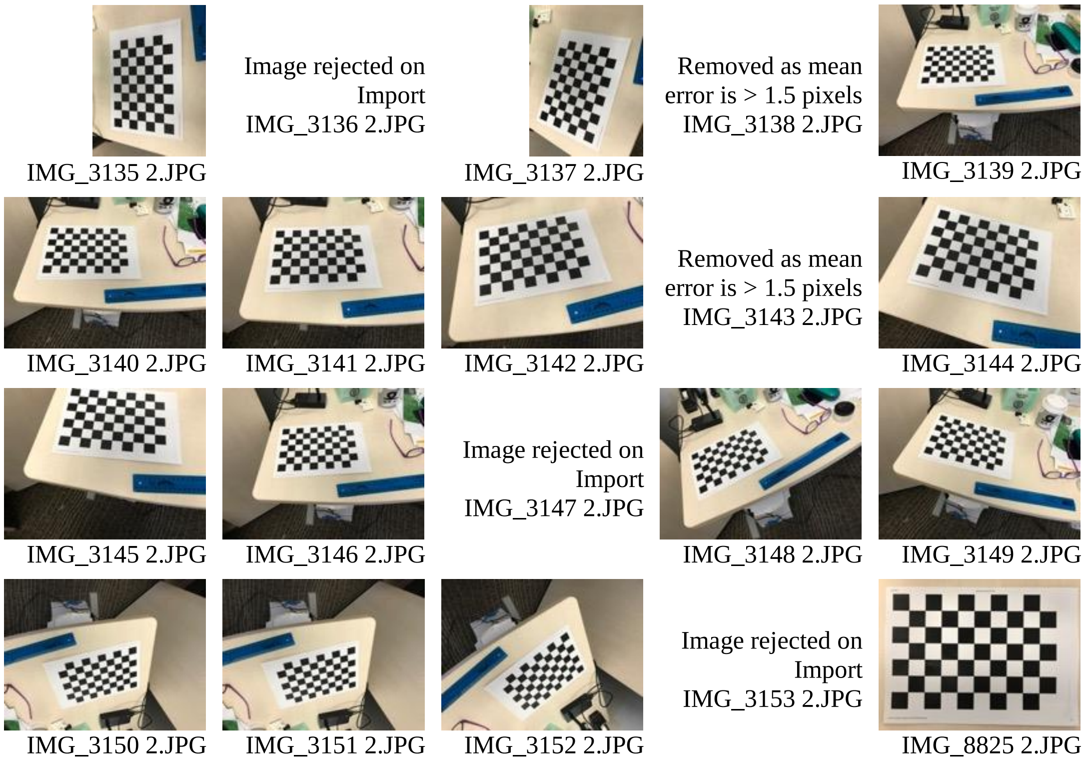


Figure 36 – All images used on camera calibration with Images rejected on import and those with a mean error > 1.5 pixel removed

5.5.2 Using an artefact to determine the difference between camera and real-world position

Background

During resuscitation, the child to be measured will most likely be on a surface, for example, a bed, or the floor; this means that the surface they are on is considered a plane and can be used as a part of the measurement process. For example, the green line in Figure 37 shows the plane that the child is on and which, therefore, can be a reference in the measurement process. As a photograph is two dimensional and the child is three-dimensional determining the height of an object/child is problematic due to the depth-of-field not being represented in the 2D photograph. In photogrammetry, this becomes an issue when the angle of the camera may cause a measurement to be incorrect due to the 3D aspects of the environment. One example of a potential error is shown in Figure 37 where the area indicated by the red circle, gives the illusion of being further away from the camera making measurement inaccurate.

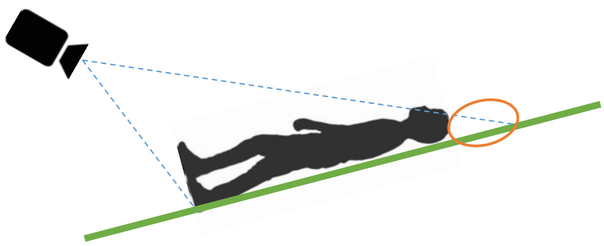


Figure 37 - Measurement of a child on a planar surface with dead space at the top of the head shown by the red circle

A straightforward solution would be to put the artefact level with the head and/or foot of the subject. This means that the artefact can mark the actual position of the head or feet and be utilised (after camera calibration) to determine the difference between camera photograph and the real-world position of the child (Figure 38 and Figure 39).

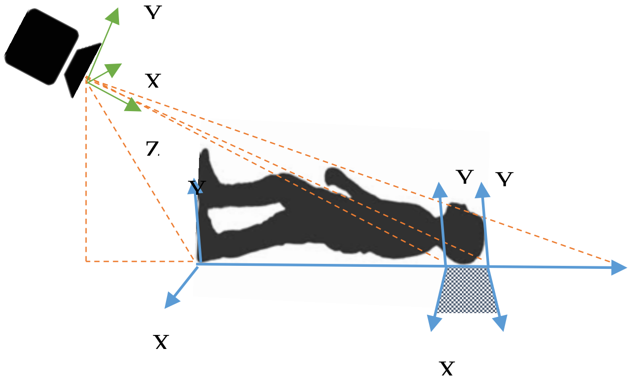


Figure 38 – Difference between planar axis (blue) and camera axis (green) for measurement in a photograph that require the use of an equation to transform and rotate these to match before measurement can occur

Figure 39 – Example of a checkerboard artefact positioned at head and foot of a child to eliminate dead space

Therefore, this experiment aims to measure an object on a planar surface with a checkerboard artefact to assist.

Design

The following experiment is to test the ability to convert a line in pixels to real-world length by analysing a photograph. Note that user input was utilised to specify the length to be measured.

Detection of the checkerboard in a photograph is an automatic class in the *MATLAB* software and is achieved usingCode Snippet 13 where it is represented in coordinates and stored in the array *imagePoints* (view from the camera). Measurements, affine transforms and rotation are then applied to these coordinates, and the measurement represented in pixels is converted to cm.

Code Snippet 13 - Detection of the checkerboard in a photograph, user input to measure the child and return the height of the child in metres and centimetres %% import image

```
I = importImage();

%% Camera Calibration - Calibrate the camera using the known checkerboard
%% return the camera parameters and some known points % in the image
disp('Callibrating camera');
cameraParams = cameraCallibration(squareSize);

%% Get the Checkerboard - Detect the checkerboard corners of each square
disp('detecting checkerboard');
[imagePoints,boardSize,~] = detectCheckerboardPoints(I);
% this takes ages look at reducing time taken
totalPoints = prod(boardSize-1);
disp(totalPoints);
width = boardSize(2);
disp(width);
topRight = totalPoints-width-1;
topLeft = 1;
% line = line(topLeft,topRight,'Color','red','LineStyle','-');

if isempty(imagePoints)
  disp('no checkerboard detected in image');
else
  %% Generate the world coordinates of the checkerboard
  % corners in the pattern-centric coordinate system, with the
  % upper-left corner at (0,0) and calculate the distortion
  % rotation.
  disp('generating worldPoints');
  worldPoints = generateCheckerboardPoints(boardSize,squareSize);
  [R, t] = extrinsics(imagePoints,worldPoints,cameraParams);

  %% display image and the
   disp('displaing image');
  figure, imshow(I);
  hold on;

  %% return the length line object detected extract start and
  % endpoint
   disp('get line');
  [line,lineLengthPixels,lineCoordinates] = getLine(I);

  %% undistort the start and end coordinates of the line
   disp('undistort line');
  worldPoints1 = pointsToWorld(cameraParams, R, t, lineCoordinates);
  d = worldPoints1(2, :) - worldPoints1(1, :);

  %% calculate the length in mm and cm
   disp('calculate line length');
  lengthInMillimeters = hypot(d(1), d(2));
  fprintf('Measured length of line = %0.2f mm\n', lengthInMillimeters);
  lengthInCM = lengthInMillimeters/10;
  fprintf('Measured length of line = %0.2f cm\n', heightInCM);
end
```

Code Snippet 14 is the function utilised to import the image for analysis and Code Snippet 15 handles the user input that identifies the area of the photograph to be measured.

Code Snippet 14 – Function to import the image to for analysis

```
function [I,info] = importImage( ~ )
%% Choose the image to analyse
folder = pwd;
cd(folder);

%% Browse for the image file.
[baseFileName,folder] = uigetfile('*.*', 'Choose an image to analyse');
fullImageFileName = fullfile(folder, baseFileName);
I = imread(fullImageFileName);
info = imfinfo(fullImageFileName);
```

Code Snippet 15 – Get the height of the child via user input

```
%% Get the length of the child via user input
function [line,length, position] = getLine(~)
  [x,y] = ginput(2);
  hold on
  line = imdistline(gca,x,y);
  api = iptgetapi(line);
  length = api.getDistance();
  position = api.getPosition();
  hold off
end
```

Implementation

The environment was set up by attaching a checkerboard pattern and orange sticky note to a cupboard door, which allowed a planar, flat and consistent surface to measure (Figure 40). This image was then analysed using *MATLAB* code in the previous section from Code Snippet 13, and Code Snippet 15.

Figure 40 - Test Image with checkerboard 23 mm squares and measurement of sticky note

The output is the blue line in Figure 40 which is 354.05 pixels equating to 52.97 mm which is a similar size to the orange sticky note in Figure 40 which measured is 50 mm. This shows that a planar object can be measured using photogrammetry to ± 3 mm or 6.7% of its actual size.

Testing

The next experiment was set up on the floor with a child-sized mannequin to measure as an alternative to the sticky note (Figure 41). As above, the image was analysed using *MATLAB* in, Code Snippet 14 and Code Snippet 15.

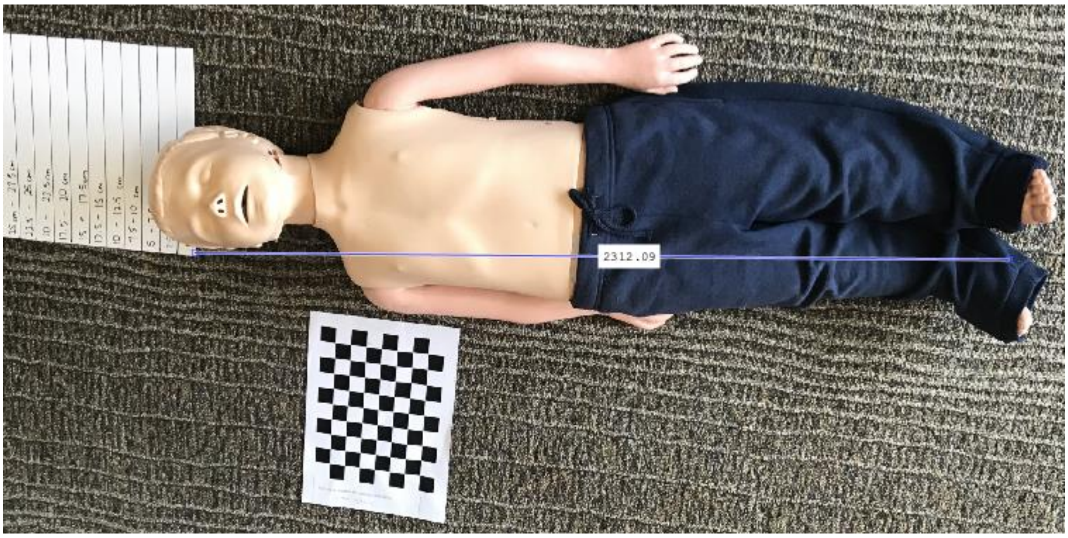


Figure 41 – Using a mannequin to measure with a checkerboard artefact, measurement is from the heel of the child to the top of the head which is level with the white cardboard shown above the mannequin

The output in Figure 41 is the blue line which measured 2312.09 pixels, which equates to 1097.91 mm. The actual size of the mannequin in Figure 41 is 107 cm (1070 mm) which shows that measurement and transformation of this larger object was accurate to ± 30 mm or 2.5% of the height of the mannequin.

Evaluation

This experiment has shown that measurement of height was accurate to between 2.5% (mannequin) and 6.7% (sticky note) of actual height when the user input identified the height of the object to be measured. What this means is that weight could be derived from measurements in a photograph given the right regression model. During this experiment user input was performed using the mouse pointer and translation to a mobile phone environment where a user taps the screen to signify input will need further validation. Furthermore, the potential for compounding error needs to be recognised, for example, error related to user input or the measurement process and error related to the conversion from height to weight.

5.5.3 Exploration of depth-of-field

Design and implementation

This experiment aims to explore the effect of depth of field in planar and non-planar objects after image analysis.

Non-planar objects are more challenging to measure than planar objects when using photogrammetry. For example, when applying the algorithm in Code Snippet 13, Code Snippet

14 and Code Snippet 15 is applied to the photograph in Figure 42 the width of the coaster was calculated to be within 2 mm of the same measurement using a ruler. However, when measuring the height of the picture frame (actual height, 120 mm), the result was 823.36 mm, which is inaccurate by 703.36 mm. This discrepancy is due to the coaster being on the same plane as the artefact and therefore having a similar perspective. Whereas, the picture frame is perpendicular to the artefact and therefore cannot be utilised without reference points that are on the same plane as the picture frame.

Figure 42 - Measurement of planar and non-planar objects using an artefact as a reference pointTo examine the depth of field further, Code Snippet 16 was used to analyse two photographs and return the height of the green drink bottle in planar and non-planar environments.

Code Snippet 16 - Measure an object based on a checkerboard artefact

```
  % return the length line object in pixels, detected extract start and
endpoint and return these in a lineCoordinates array
  [line,lineLengthPixels,lineCoordinates] = getLine(I);

  % set the line start and line end from the array of line coordinates
  lineStart = lineCoordinates(1);
  lineEnd = lineCoordinates(2);

  % undistort the start and end coordinates of the line
  worldPoints = pointsToWorld(cameraParams, R, t, lineCoordinates);
  d = worldPoints(2, :) - worldPoints(1, :);

  % calculate the length in mm
  lengthInMillimeters = hypot(d(1), d(2));
  fprintf('Measured diameter of line = %0.2f mm\n', lengthInMillimeters);
```

Testing

Once the checkerboard and transform information is available this can be used to measure objects in the photograph. For example, in Figure 43 the drink bottle shown (measured 260 mm with a ruler), is on the same plane as the checkerboard on the computer screen. Using Code Snippet 16, the drink bottle was measured as 234.01 mm, just over 90% of its actual measured size.

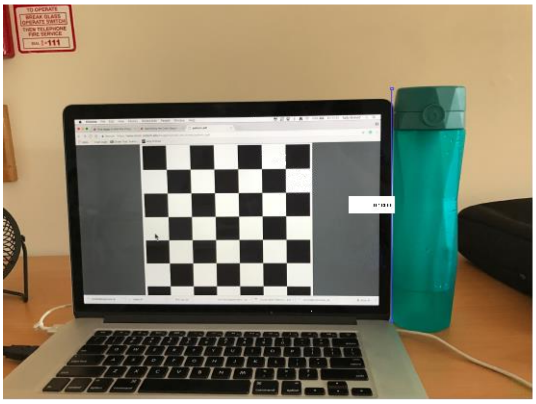


Figure 43 - Image of object to be measured on same plane as checkerboard

When Code Snippet 16 was applied to Figure 44, the output showed that the blue line measured 508.94 mm while the actual size of the drink bottle measured was 260 mm. To give some perspective, the algorithm measured the drink bottle as 249 mm (24.9 cm) larger than the size measured with a ruler. What this illustrates is that the distance from the checkerboard (depth of field) impacts the measurement of objects when using photogrammetry.

Figure 44 - Photograph with checkerboard artefact and object at different distances to illustrate the need for these to be on the same planar surface for measurement

Evaluation

According to Wohler,[243] many methods in image processing could be utilised in the measurement of non-planar objects, for instance, detection of objects using shading and light. A disadvantage that he noted for many of these methods was the need for a pre-determined camera setup which does not match the need for variability in the resuscitation environment.[243] However, a simple solution does exist. In the resuscitation environment, subjects are generally already on a planar surface, such as the ground or a bed. Therefore, the configuration identified in Figure 39 where the child and checkerboard were always found on the same plane could be included as a known limitation of the software, with users learning that a plane perpendicular to the artefact (checkerboard) cannot be measured.

5.6 Chapter Summary

Firstly this chapter revisited the aim of this research, and the impact of ad-hoc changes to weight estimation in paediatric resuscitation was discussed.

A series of experiments were designed to investigate the applicability of potential solutions to providing a mobile weight estimation using photogrammetry. Experiments varied and included investigation of mathematical principles and photogrammetry along with utilising sensor data and EXIF information stored in photographs to aid image processing. Further experiments investigated the detection of a child in a photograph using grey and colour thresholding, edge detection, existing algorithms and foreground and background detection. Measurement in a photograph was also investigated along with the use of an artefact positioned to assist as well as the effect of depth of field on measurement.

This series of experiments have identified both advantages and disadvantages to the methods tested in this chapter (Table 19). The information gathered in the experiments has shown where further development is required and has informed the redefined acceptance criteria which are outlined in Table 20. These findings and revised acceptance criteria will be applied in the following chapter which outlines the development of the WEWW application.

Table 19 - Overview of experiment results with advantages, disadvantages and requirements for development of the WEWW application

Method		Advantages	Disadvantages	Requirements
Potential Mathematical Solutions	Pythagoras Theorem EXIF data to apply in Pythagoras theorem	Simple calculation. Stores some variables required in Pythagoras Theorem.	Missing data required – e.g. distance from the camera to the child.	Static environment or known variables.
	The angle of elevation and depression	Angle of elevation and depression can be obtained from mobile phone data.		
Mobile Phone Sensor Data	Gyroscope accuracy	Gyroscope is accurate to ±1.63° Returns angle of elevation and depression.	Potential for compounding measurement error.	
Object Detection	Thresholding Existing edge detection algorithms Colour segmentation	Determine the outline of an object in a photograph. Accurate with a consistent coloured and textured object and background.	Poor quality in multi-coloured objects. Poor quality in “noisy” busy photographs. High CPU usage.	Consistent coloured object and background. Static photograph. Could be included with other data in calculations.
	detectPeople class Foreground and Background detection	Built-in class to detect people in photographs. Determine the silhouette of a person.	Poor detection, large boundary. Still background and moving foreground or vice versa.	Not conducive to resuscitation environment.
	User input for object detection in photograph	Accurate when tested by the developer. No CPU or time constraints. Compensation for hidden objects and space by the user. The user can correct dead space.	Dependant on user input. Potential for user error	Detailed user instructions.
Measurement in a photograph	Black and white checkerboard	Uniform pattern. Easily detectable colours. Well established in the literature.	Needs to be portable and useable in varied environments.	Specific square size in checkerboard or user-specified size.
	Camera Calibration	Ensures accurate affine and transform to measure objects in a photograph. Allows refinement of measurement parameters.	Introduces the risk of compounding error. Future handling of this may be needed for different devices.	Unknown acceptable error for reprojection errors.
	Restriction to an object on the same plane for measurement	Accurate when tested. Most likely to be required in a resuscitation environment.	Excludes non-planar measurement.	User instruction required to ensure planar measurement is initiated. Restricted to planar measurement only.
	Affine transformation.	Allows easy transformation between real-world view and flat view for measurement.	Complexity.	

Table 20 - First iteration of the revised acceptance criteria

	First Updated Acceptance Criteria
Mobile	
1	WEWW application developed for iOS (iPhone)
Accuracy	
2	Estimate weight for > 75% of sample to within 10% of their actual weight
3	Demographic characteristics utilised increase accuracy
NZ dataset	
4	Based on the NZ dataset to increase accuracy
Environment	
5	Usable in a varied environment (e.g. non-static environment)
	Offline use
User Input	
6	User input for object detection
7	Minimal and simple (to decrease cognitive load)
Measurement	
8	Use of checkerboard artefact of known measurements.
9	Planar surface measurement (x axis) only with artefact (checkerboard) on same plane as child.
Positioning	
10	Artefact and child on same planar surface

6 Chapter Six – Application design and initial development

6.1 Introduction

Designing an application for a mobile environment introduces characteristics and constraints that can influence design decisions.[246] This chapter will identify the purpose and users of the mobile application Weight Estimation without Waiting (WEWW) and discuss development considerations such as the mobile context, information privacy, and others. It will then explore the initial development of the backend and frontend up until the user testing phase.

6.1.1 Purpose of the WEWW application

Based on the acceptance criteria identified in section 5.6 (Table 20) the following statement was developed to give an overview of usage and purpose of the WEWW application.

> The mobile iOS application Weight Estimation without Waiting will return an accurate weight and calculate body surface area from this for New Zealand (NZ) children in multiple environments, with and without mobile phone coverage. The user interface will be simple with weight estimates tailored to children by using NZ specific data and demographic characteristics to increase the accuracy of weight estimates.

6.2 Design Considerations

Some external contexts, such as the users, legislation and mobile context can influence the design and development of the WEWW application as well as the acceptance criteria. Therefore, the following design considerations explore the rationale for decisions that underpin the development of the WEWW application. They are presented at the beginning of this chapter to give context prior to a description of the application development.

6.2.1 Mobile context

Software design for the mobile phone has different needs than a traditional computer-based design. Key differences unique to the mobile context include smaller screen size, inferior connectivity, lower display resolution, and limited processing power and data entry methods.[247] Furthermore, the need for battery power and recharging also needs to be considered in the development of the WEWW application.

One of the first design decisions required was whether to design a web-based or native application.[246] The following exploration of the deployment environment, need for information privacy, user characteristics and regulation of health-related software led to the decision to make an offline native application starting with the iOS platform.

6.2.2 Deployment environment

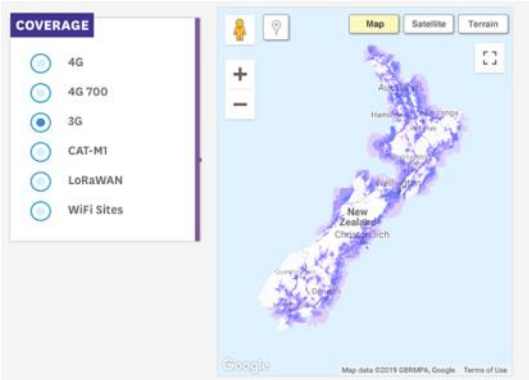
The deployment environment for the WEWW application is one where advanced paediatric resuscitation is required. In this case, advanced resuscitation is a situation where intervention by healthcare professionals trained to provide advanced resuscitation are doing so in a situation where equipment and resuscitation drugs are available.[248] In NZ there are two primary environments where the WEWW application is most likely to be deployed:

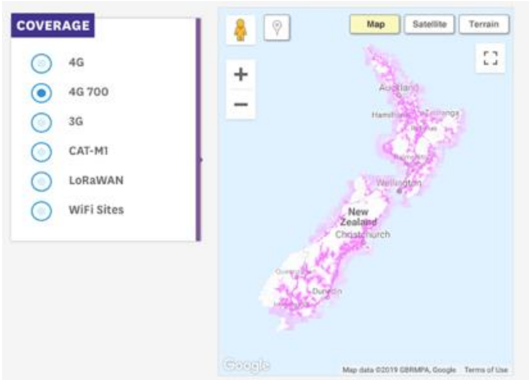
- **Prehospital**/Ambulance/Military/The Primary Response in Medical Emergencies (PRIME) Team
- **Hospital**/Paediatric ED/Paediatric Intensive Care

Chapter One – Introduction gave an overview of prehospital and hospital resuscitation environments and revealed that versatility and adaptability of the environment are required to provide optimal treatment during paediatric resuscitation. This is backed up by Luten[7, 8] who characterises the resuscitation environment as fast-paced, decision-dense and often unpredictable, showing that constant problem solving and versatility are required.

In a hospital, this means that, while the environment may be in the same physical space, the equipment and layout may differ across facilities and at different points during the treatment. Similarly, it is difficult to anticipate the prehospital environment as accidents, injuries and medical conditions can occur at any geographical location. This means that the design of the WEWW application needs to account for this variability. For example, it needs to be usable on a portable mobile device and adapt to different needs, such as uneven terrain, unpredictable weather or lighting and even lack of cell phone coverage.

As an example, Figure 45 shows Spark (a NZ mobile provider) data coverage maps. This pinpoints that there are areas of NZ that have no cell phone coverage. This example only shows one mobile provider, and if this application were designed to rely on connectivity, all providers coverage would need to be mapped. However, as discussed later in this chapter, working offline is important for more reasons than mobile coverage.





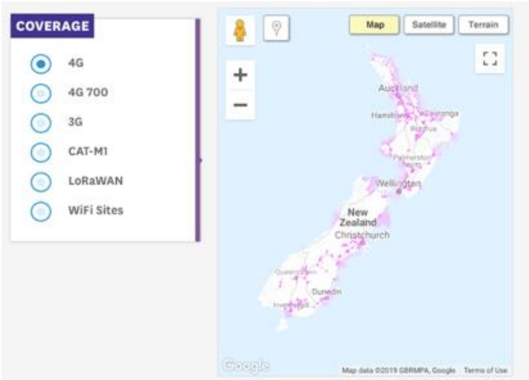


Figure 45 - Spark 3G cell phone coverage (top left), Spark 4G 700 cell phone coverage (top right) and Spark 4G cell phone coverage (left).[249]

Mobile data coverage would be essential to this application if, for example, the design would utilise a server/client approach for image analysis and, therefore, weight estimation. Due to the patchy mobile coverage illustrated in Figure 45 and legislative requirements around information privacy and security,[250] the design of this application will be as a native application for offline use only.

6.2.3 Information privacy and security

The storage of health information and the image itself causes a dilemma. The Health Information Privacy Code 1994[226] and subsequent amendments along with Health Information Governance Guidelines[251] outline the legal and ethical obligations concerning patient data storage and transmission in NZ. Even though designing and using innovative technology such as the WEWW application aligns with the NZ Ministry of Health Vision for Health Technology[252] by informing and individualising patient care using technology, the photograph is still considered health information, and even if it is only for image processing and then deletion, it requires both legal and ethical consideration. In the clinical arena, this means that patient, parent or guardian informed consent[253] is required alongside specific security measures[254] to ensure the privacy of patient information.

Optimisation in application design is an essential consideration in the mobile context. For example, the impact of image processing or transmission of data from a mobile device can affect the time to treatment and, ultimately, the survival of the child undergoing resuscitation. Using a server-client or cloud model can reduce energy or battery use and enhance performance.[255] However, it could be argued that a standalone design working around constraints such as limited battery life, memory and storage could also impact the time to treatment in a resuscitation environment. Finding the balance between time to treatment and hardware or software constraints creates a trade-off for healthcare-application developers.

One area of risk is when a user chooses to take a screenshot while using the WEWW application. At this point, there is no way to disable altogether screenshot-taking in iOS, which makes this a potential area of risk in breaching privacy.[250] While a client-server application could potentially increase the processing power for image analysis and thus decrease time to treatment, a risk of privacy breach during transmission is higher as there are often multiple types of technology required (including networks, databases, operating systems, load balancing, and memory management),[250] all of which could offer a potential point of privacy breach.

With the security of health information in mind, one solution in the development of the WEWW application is removing the need to store or analyse an image on the device. However, the transmission of the image to a server for analysis could also increase time to treatment. In response to this dilemma, the WEWW application has been designed to gather environmental information, such as the distance to the floor or plane the child is on, without storage or transmission of data. What this means is that image analysis is minimal, with video from the camera streaming to the screen without any analysis being done after the initial detection of the plane the child is on.

Designing the WEWW application not to store an image of the child only mitigates a portion of the risk to patient privacy; other data such as demographic information and the measured length and weight could also pose a potential threat. Though, it is worth noting that the collection of data may be helpful in a future implementation. For example, adding machine learning or artificial intelligence (AI) capabilities may be an option to ensure the ongoing accuracy of the WEWW application to match the change in population characteristics over time. With this in mind, the introduction of data storage requires consideration of access control, which is not a part of the current research. Therefore, this application will not collect, store or transmit any patient data, with the knowledge that this may need further investigation and careful consideration of privacy if it were to become an option for future development.

6.2.4 Users

The New Zealand Resuscitation Council (NZRC) manages guidelines for paediatric resuscitation in the prehospital and hospital settings.[18, 66, 248] NZRC Guidelines specify weight estimation techniques clinicians use in paediatric resuscitation. While there is variation between sectors' policies on weight estimation technique for children over nine years of age,[18, 36] for younger children weight estimation techniques are the same. Another area that remains constant is the healthcare professionals themselves, however, they often work across varying resuscitation environments, for example, the junior doctors in NZ change clinical environments and even district health board every three to six months which could have an impact on ad-hoc changes to weight estimation.

Users of the WEWW application are health professionals who need to estimate the weight of a child during resuscitation. This group of healthcare professionals is a subset of all healthcare professionals and is most likely to be prehospital emergency care staff, registered nurses and medical doctors working in a paediatric emergency. In NZ, both nurses and doctors are professionals who are registered and practice under the Health Practitioners Competency Act 2003.[256] They both report to a registration body that has legal and ethical standards governing practice.[257, 258] Furthermore, paramedics are actively working towards becoming a registered body in NZ,[259] which means the professions that are likely to use the WEWW application have a code of conduct with ethical and legal obligations when providing healthcare.

Defining this subset of users is an essential consideration in understanding the limited pool of healthcare professionals who may use the WEWW application the narrow context that surrounds the deployment of the WEWW application. Therefore, future post-doctoral work will include exploration of distribution, regulation and education around the application for healthcare professionals to ensure patient safety.

6.2.5 Regulation

Some regulation of medical devices exists in NZ through the Medicines Regulations Act 1984,[260] however, this generally refers to hardware with strict rules around distribution and advertising. Regulation of mobile applications, such as WEWW, in the health sector is not in place currently for NZ.

The NZ Ministry of Health provides guidelines for evaluation and development of health applications,[88] however, on the review of these guidelines, directions appear only to apply to the design of consumer-focused applications or those providing information directly to the public. What this shows is that a lack of direction exists for designers of applications for sole use by healthcare professionals. Currently, some guidance is available around maintaining the privacy of health information through the Health Information Security Framework,[254] but other standards related to the development of health software are either planned for the future or currently being developed.[261]

The standards currently under development or planned include interoperability, digital identity and connected health networks.[261] However, a publication date for these is unknown, and the plans do not appear to include advice on the development of standalone applications for use by healthcare professionals. What this highlights is the need for further governance in stand-alone health application design and development.

With the ongoing development of policy surrounding technology in healthcare, further development of the WEWW application may be required to meet future health technology standards. Thus, in anticipation of future standards or guidelines, the decision to make the WEWW application modular, native and stand-alone will make any subsequent development or refinements less cumbersome. Table 21 outlines the design considerations to be implemented in development of the WEWW application.

Table 21 - Design Considerations

Design Considerations
Design
Modular to allow for easy updates
Native for offline use
Users
Healthcare professionals trained in advanced paediatric resuscitation
Healthcare professionals who are registered, with a code of ethics and legislated practice
User Interface
Small, low resolution screen
User Input
Fast, minimal, simple
Image Analysis
Limited processing power of mobile devices
Environment
Usable in multiple environments adaptable to conditions required
Storage
No information or data stored

Implementation

This section will apply the acceptance criteria (Table 20) and design considerations (Table 21) to the user workflow and update the acceptance criteria based on the workflow considerations outlined below.

6.2.6 User Workflow

From my observation of other healthcare professionals (over eight years) while working in a dedicated children's Emergency Department (ED) and volunteering as a front-line ambulance officer, I found the weight estimation process workflow to be non-standard between settings. Furthermore, the ambulance role was heavily procedure-based as ambulance staff are not a registered profession and work under an 'authority to practice' using procedures where the medical director is ultimately responsible. Whereas, the hospital adopted a more ad-hoc method as staff in resuscitation are registered professions and therefore are clinically responsible. With a reliance on working within procedures (ambulance), there is little leeway to alter an incorrect weight estimate, however in the hospital setting these ad-hoc changes are common. While both the prehospital and hospital settings generally used the same age-based weight estimation method, the ad-hoc changes made by hospital staff to adapt to the needs of the changing population led to the investigation of weight estimation workflows in more detail. This investigation of workflows was a precursor to beginning prototype design where a standardised system was likely to be implemented.

Traditional weight estimation workflow

As established earlier in this thesis (sections 1.7 and section 4.2.1) and in literature[14] clinicians may adapt weight estimation results in an ad-hoc manner based on the look of the child requiring resuscitation. What this adaptation shows is a need for alteration of the guidelines for weight estimation to match the needs of the NZ population. When analysing the workflow at the inception of this thesis the NZRC guideline did not address an alternative weight estimation method if the age-based formula was not appropriate.[53] Figure 46 illustrates the workflow for estimating the weight of children using the NZRC guidelines that were in place at the inception of this research.

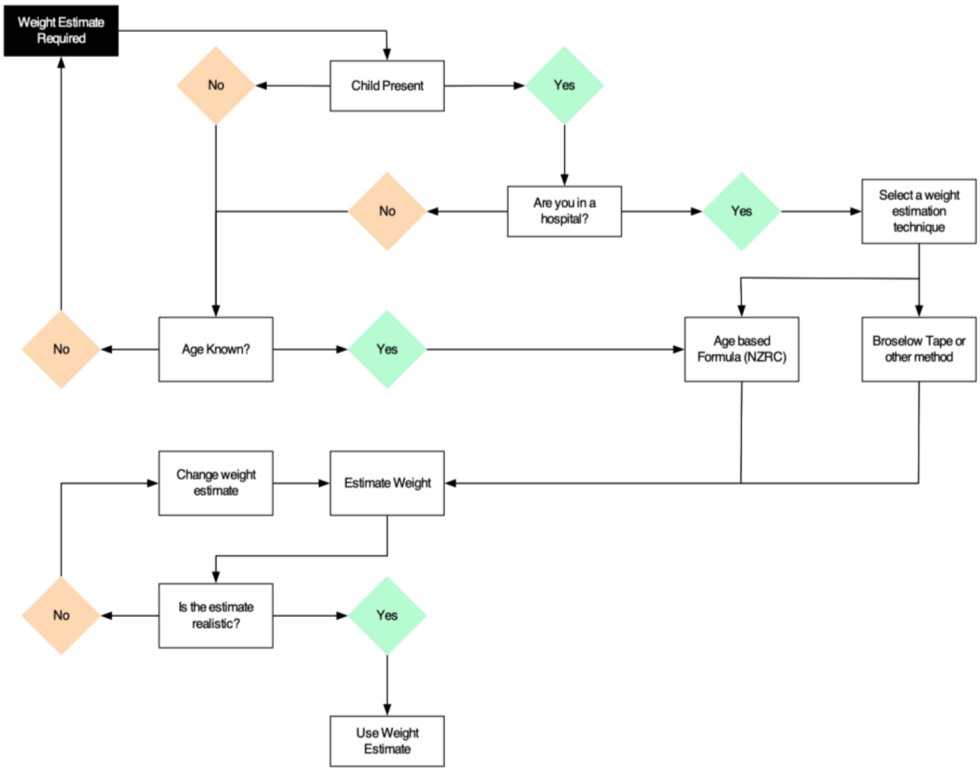


Figure 46 – Weight estimation workflow based on guidelines in place at inception of this research[53]

The current NZRC Guidelines for Advanced Paediatric Resuscitation released in 2016[18] partially address the ad-hoc adaptations by clinicians; these new guidelines suggest the use of length-based weight estimation if a child looks obese, which has altered the original workflow with the changes shown in Figure 47.

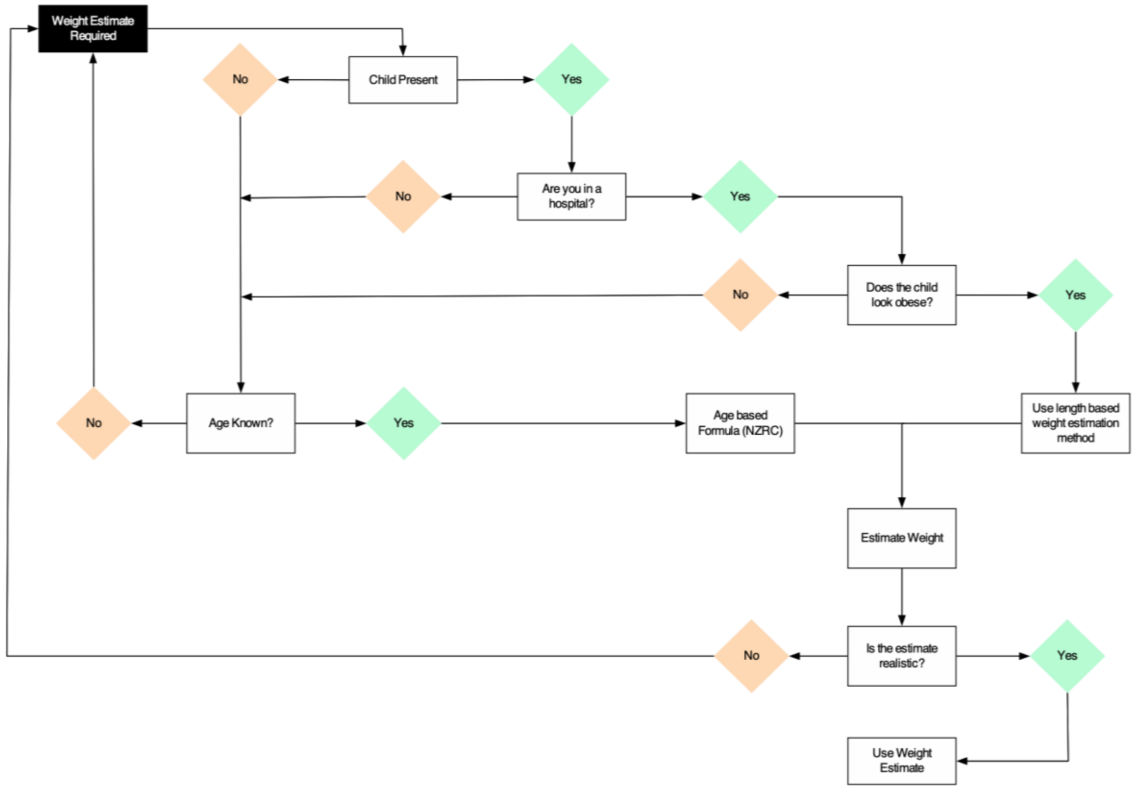


Figure 47 - Change to the weight-estimation workflow in the 2016 NZRC guidelines

WEWW weight estimation workflow

The workflow for weight estimation was streamlined in the design of the WEWW application while adhering to the NZRC Guidelines[18] by ensuring the questions for the user only required binary decisions (Figure 48). Thus, user questions have been simplified by framing them as requiring simple “yes” or “no” answers and removing the more complex choices.

One could argue that the use of the WEWW application requires the child to be present and for this reason, the traditional Advanced Paediatric Life Support (APLS) formula may be preferred by clinicians as a method for estimating weight. However, utilisation of APLS formula could become decision-dense due to the known inaccuracy of this method when used on NZ children which initiates the need to sanity check the weight estimate when the child arrives. Decision density can be reduced further by removing the need to choose a weight estimation method such as APLS or the Broselow-Luten Tape.

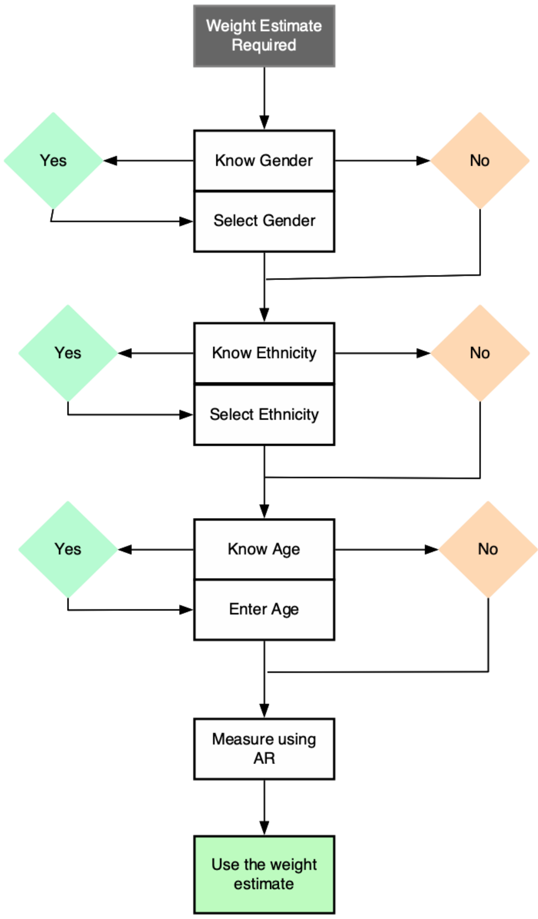


Figure 48 - Workflow using WEWW to estimate weight

A summary of the differences between workflows can be seen in Table 22.

Table 22 - Comparison of workflow characteristics

	Steps	**Interactions (non-binary decisions)**	**Binary Decisions**	**User task or calculation**	**Potentially Cyclic Process**
Initial Workflow (Figure 46)	6+	5	3	1	Yes
Revised Workflow (Figure 47)	6+	2	4	1	Yes
WEWW Workflow (Figure 48)	7	1	3	1	No

An overview that translates the WEWW workflow into software design processes is shown in Figure 49 which displays a timeline of the workflow in relation to functions of the WEWW application.

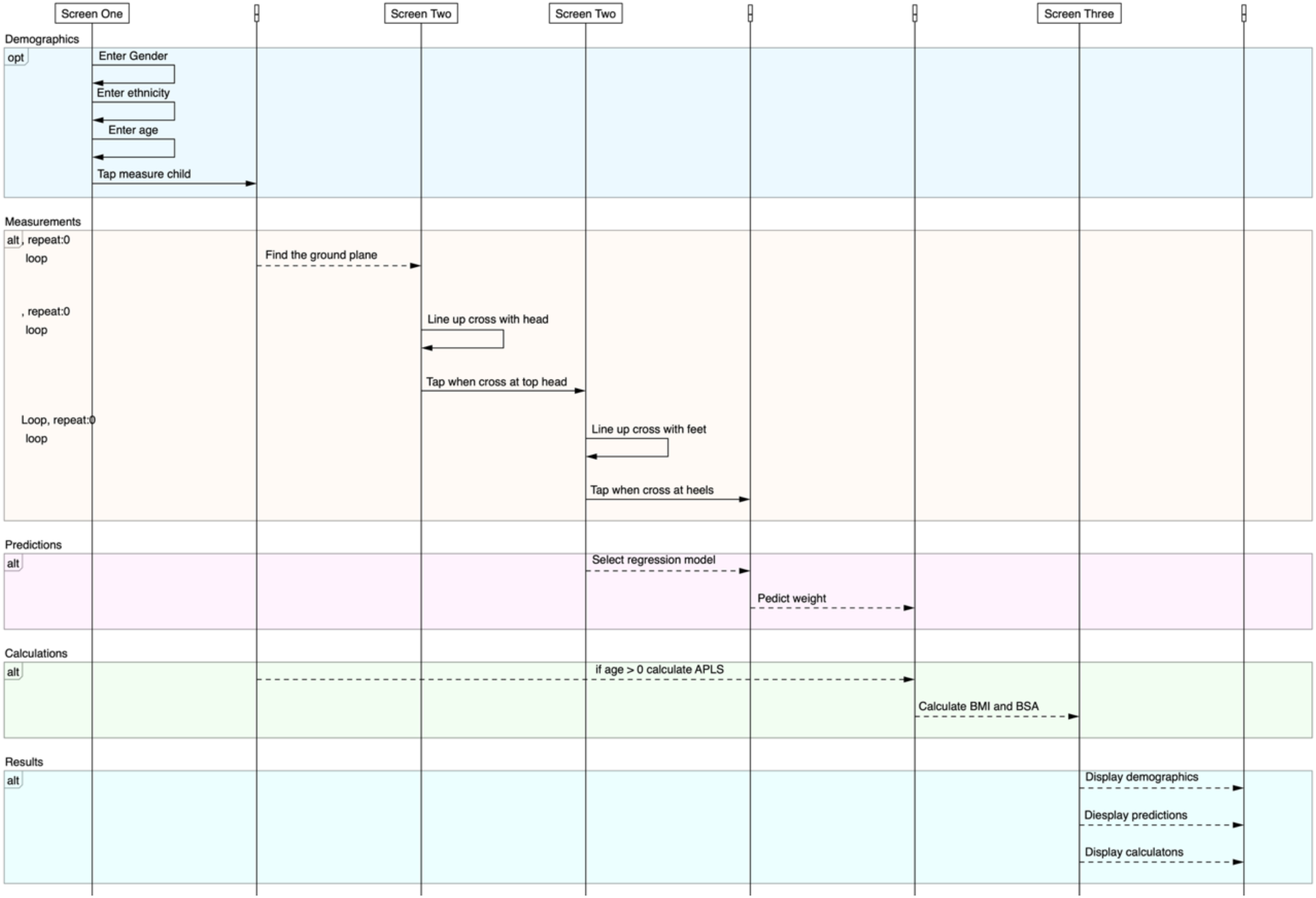


Figure 49 – Timeline of the functions associated with the WEWW application using an UML Sequence diagram in Software English

With the readability of this thesis in mind, the development of the graphical user interface (GUI) is discussed next rather than the backend, which was initially developed straight after the workflow analysis.

In software development, the GUI and backend are often separated. The GUI handles or initiates user input while the backend manages the processing that is not seen by the user, and the delineation of these can be seen in Figure 50 which shows the relationship of the GUI and backend with the main GUI components in the box and supporting classes outside of the box.

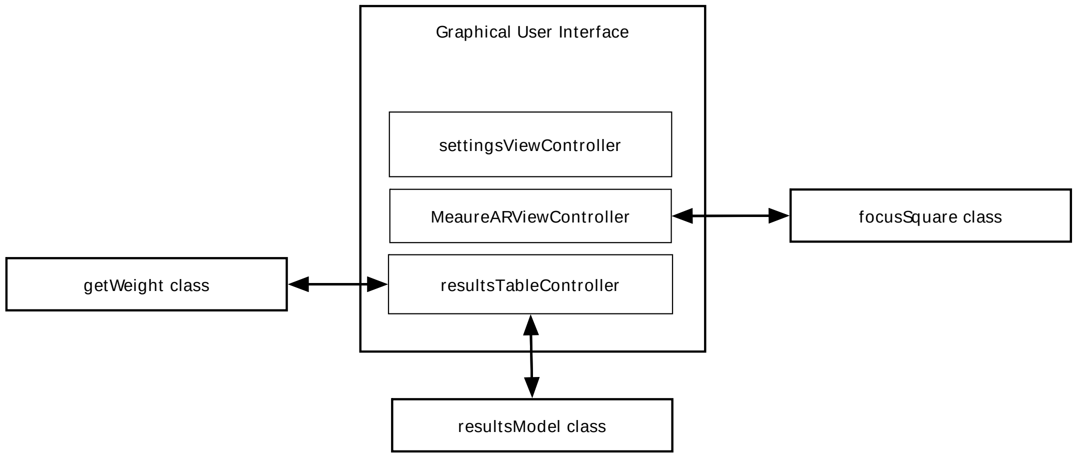


Figure 50 - Overview of structure of the WEWW application

For more detail on the overall structure of the WEWW application, a uniform modelling language (UML) diagram is available in Appendix G – UML diagram for the WEWW application.

6.2.7 Application design

MATLAB (version 2017b)[211] was initially used in prototyping the WEWW application; however, at the time prototyping of the WEWW application began, *MATLAB* computer-vision components were not portable to the iOS[262] development platform to provide native functionality. After a phone consultation with Dr Andrew Ensor,[263] a Senior Lecturer at Auckland University of Technology who specialises in computer vision, several different options to manage computer-vision integration for the WEWW application development in iOS were identified. Upon further investigation of Apple developer tools, the use of OpenCV[264] libraries appeared to be the most straightforward platform approach for achieving the photogrammetry needs of this project.

Fortunately, the development of the WEWW application began the same week that Apple Inc. launched *ARKit*[265] (September 2017). *ARKit*[265] provided the computer vision functionality required for the development of native iOS applications using computer vision and machine learning. Therefore, a decision was made to continue the development of the WEWW application using *ARKit*[265] functionality in the *Swift*[266] and *Python*[267] programming languages supported by Apple Inc. which were then able to be implemented natively on an iPhone[268] rather than the planned OpenCV[264] libraries. For these reasons, the acceptance criteria have been updated, removing the need for an artefact (Table 23), as *ARKit*[265] manages this automatically.

Table 23 - Second revised acceptance criteria

Acceptance Criteria	
Mobile	
1	WEWW application developed for iOS (iPhone)
Accuracy	
2	Estimate weight for > 75% of sample to within 10% of their actual weight
3	Demographic characteristics utilised increase accuracy
4	Based on the NZ dataset to increase accuracy
Environment	
5	Usable in a varied environment (e.g. non-static environment) Offline use
User Input	
6	User input for object detection
7	Minimal and simple (to decrease cognitive load)
Measurement	
8	Augmented Reality (AR) to detect planar surface with measurements calculated in relation to the detected plane
Positioning	
9	Artefact and child on same planar surface

N/A is not applicable

Graphical user interface (GUI) design

The WEWW workflow outlined in Figure 48 was used to design an initial user interface consisting of three screens (labelled 1, 2 and 3) shown in Figure 51. The first GUI design included a test screen, which would allow the people who were performing accuracy testing to enter data related to the child. However, the test screen was removed for user testing and not included in the final prototype.

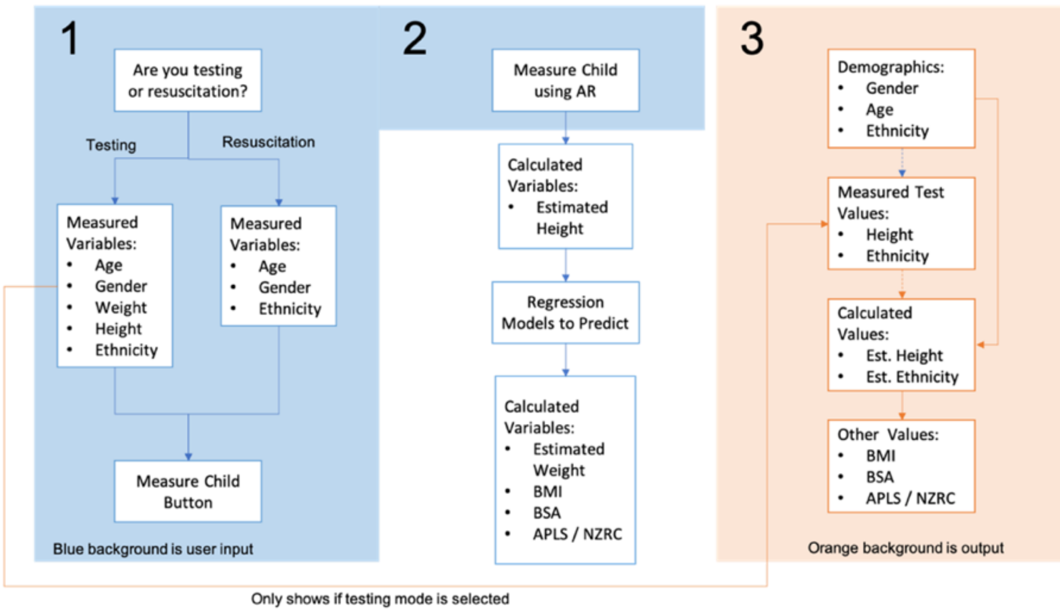


Figure 51 - Initial user interface for resuscitation user input

The GUI layout initially used equal sized and spaced stacks[269] to display the GUI, with user input triggering the visibility of the next component. This layout was chosen to ensure the user was not distracted by non-uniform elements and followed the logical workflow of the WEWW application (Figure 48). Furthermore, stacks allowed for rapid prototyping and functionality testing with screens outlined in Figure 51 and shown in Figure 52.

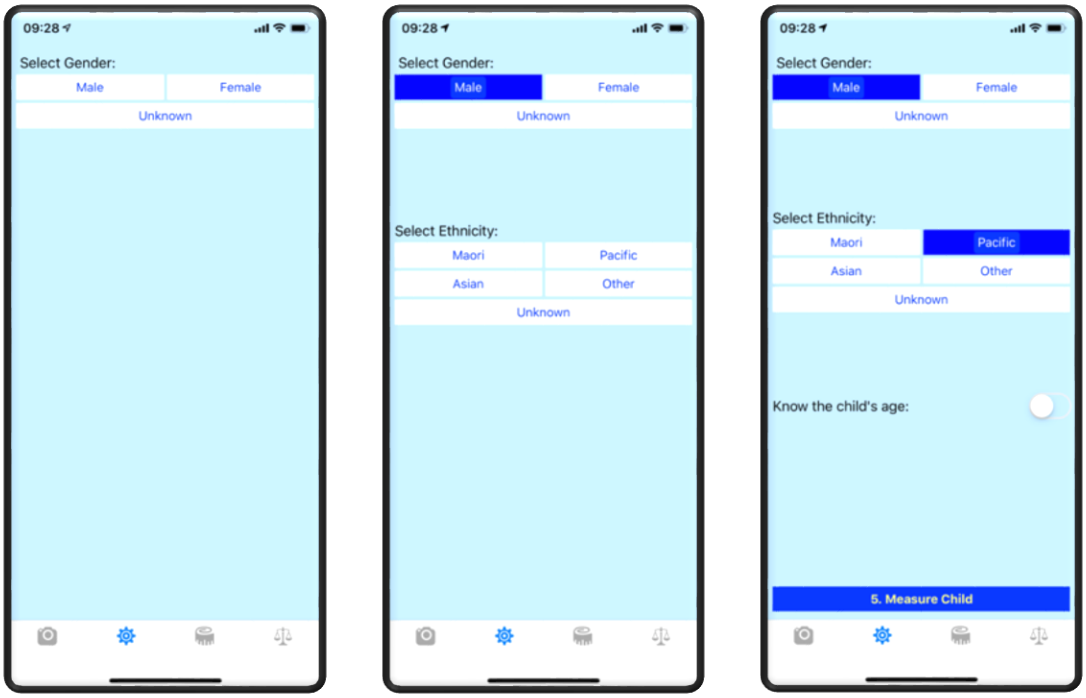


Figure 52 - Screen one (stack design), where users are presented with one decision at a time with questions appearing at completion of the previous one

Screen one is controlled by the *settingsViewController class* (Figure 53) that gathers demographic information and initiates the measurement of a child. *Swift*[266] code for the *settingsViewController* can be found in section 10.6.4 in Appendix F – Code.

settingsViewController:class
ageText: UITextField ethnicityLabel: UILabel genderLabel: UILabel ageLabel: UILabel measureChildButton: UIButton maleButton: UIButton femaleButton: UIButton unknownGenderButton: UIButton maoriButton: UIButton pacificButton: UIButton asianButton: UIButton otherButton: UIButton unknownEthnicity: UIButton Var firstRun: Bool
viewDidLoad() viewDidAppear(_ animated: Bool) viewDidDisappear(_ animated: Bool) measureChild(_ sender: UIButton) inserTextFieldShouldReturn(_ sender: UIField) -> Bool setHighlight(sender: UIButton) maleGenderAction(_ sender: UIButton) femaleGenderAction(_ sender: UIButton) unknownGenderAction(_ sender: UIButton) maoriEthnicityAction(_ sender: UIButton) pacificEthnicityAction(_ sender: UIButton) asianEthnicityAction(_ sender: UIButton) otherEthnicityAction(_ sender: UIButton) unknownEthnicityAction(_ sender: UIButton) setAge(sender: UITextField) unhighlightEthnicity() unhighlightGender() didReceiveMemoryWarning()

Figure 53 – *settingsViewController* class Diagram

Screens two and three also use a stack-based layout to standardise the look and feel of the WEWW application. The *MeasureARViewController class* controls screen two (Figure 54) which manages the measurement of the child using the augmented reality (AR) functions in *ARKit*[265]. *Swift*[266] code for the *MeasureARViewController class* can be found in section 10.6.5 in Appendix F – Code of this thesis.

MeasureARViewController:class
sceneView: ARSCNView distanceLabel: UILabel trackingStateLabel: UILabel startNode: SCNNode endNode: SCNNode dragOnInfinitePlanesEnabled = false focusSquare: FocusSquare
prepare(for segue: UIStoryboardSegue, sender: Any?) viewWillAppear(_ animated: Bool) viewWillDisappear(_ animated: Bool) viewDidLoad() setUpLabels() didReceiveMemoryWarning() handleTapGesture(sender: UITapGestureRecognizer) setUpSphere() renderer(_ renderer: SCNSceneRenderer, updateAtTime time: TimeInterval) func updateFocusSquare() session(_ session: ARSession, cameraDidChangeTrackingState camera: ARCamera)

Figure 54 - MeasureARViewController class

The *MeasureARViewController* handles user interaction on the iPhone touch screen and the measurement of the child by translating the real-world points that the user taps on the smartphone screen, into coordinates that the phone can use to calculate the height of the child being measured. To achieve this, the *MeasureARViewController* class creates a *focusSquare* (Figure 55 and Figure 56) which detects the ground plane using the distance-to-focus method automatically available in *ARKit*.[265] It tracks position, and provides a vehicle to collect measurements of the child in relation to the plane he or she is on. The *Swift*[266] code for the *focusSquare* class can be viewed in section 10.6.10 in Appendix F – Code of this thesis, with the photogrammetry component of this process discussed further in the section labelled Backend on page 114 of this thesis.

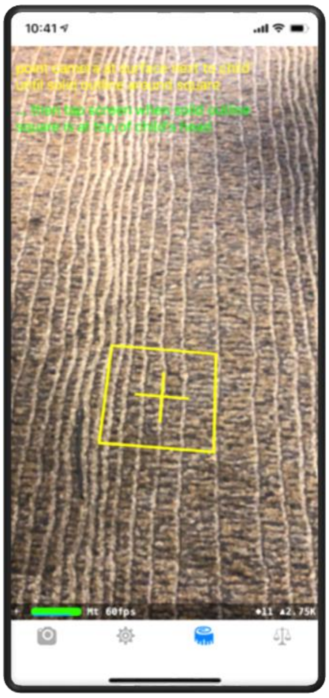


Figure 55 – Measure using augmented reality screen

focusSquare:class
focusSquareSize: Float focusSquareThickness: Float scaleForClosedSquare: Float sideLengthForOpenSquareSegments: CGFloat animationDuration: Double focusSquareColor: Colour focusSquareColorLight: Colour isOpen: Bool anchorsOfVisitedPlanes: Array isAnimating: Bool var segments: [FocusSquareSegment] fillPlane: SCNNode entireSquare: SCNNode FocusSquareSegment: SCNNode
override init() update(for position: SCNVector3, planeAnchor: ARPlaneAnchor?, camera: ARCamera?) hide() unhide() updateTransform(for position: SCNVector3, camera: ARCamera?) normalize(_ angle: Float, forMinimalRotationTo ref: Float) -> Float func scaleBasedOnDistance(camera: ARCamera?) -> Float pulseAction() -> SCNAction stopPulsing(for node: SCNNode?) open() close(flash: Bool = false) flashAnimation(duration: TimeInterval) -> SCNAction scaleAnimation(for keyPath: String) -> CAKeyframeAnimation focusSquareNode() -> SCNNode

Figure 56 - FocusSquare Class

The user then taps the screen on the patient's head and heel (in no particular order). The second tap triggers calculations of weight and calls the *resultsTableController* class (Figure 57). Results are then displayed using the screen layout shown in Figure 58 the *Swift*[266] code for the *resultsTableController* can be found in section 10.6.8 in Appendix F – Code.

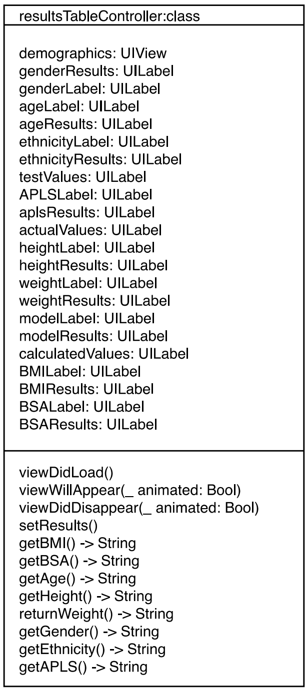


Figure 57 - resultsTableController class

Figure 58 - Screen three layout

The *resultsTableController* class first calls the *setResults* class that creates a *resultsModel* (Figure 59). The results model assigns the appropriate regression model based on the available user-selected criteria (age, height, ethnicity or gender) for prediction and then applies it. With the predicted result it calls the *getWeight* (Figure 60) class to return a modelled string containing the results. The *Swift*[266] code for *resultsModel* and *getWeight* is shown in Appendix F – Code in section 10.6.9 and 10.6.6, respectively.

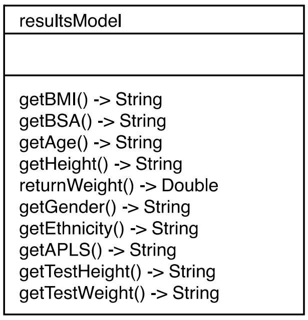


Figure 59 - *resultsModel* class

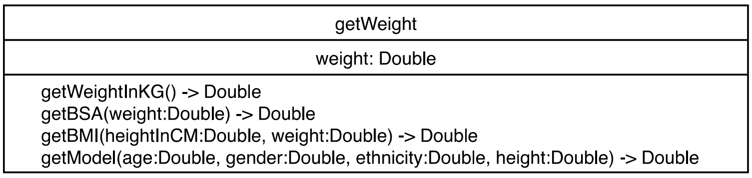


Figure 60 - *getWeight* class

6.2.8 Backend

The backend of the WEWW application houses the functionality that the user does not see visually. The backend comprises of logical functions which take the user input and determine a weight estimate from this. Figure 61 gives a macro level overview of the backend design for the WEWW application with concepts such as the regression models/equations being discussed later in this chapter.

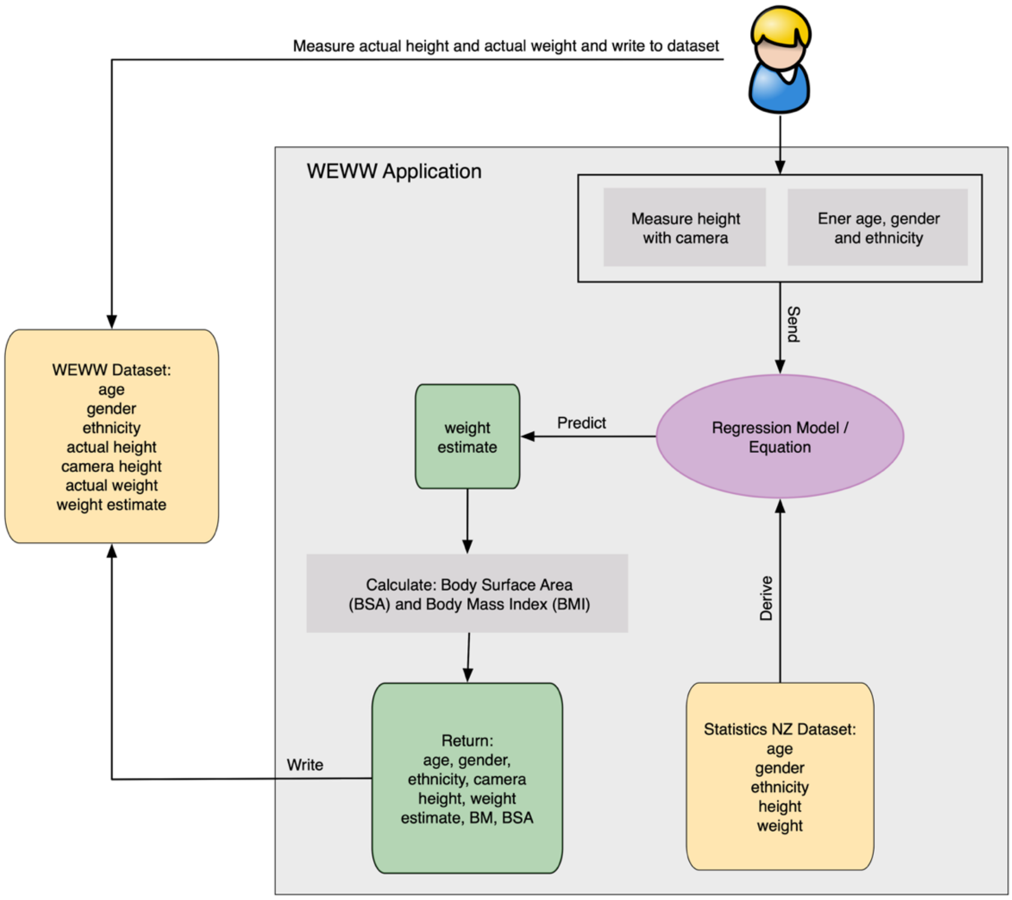


Figure 61 - Macro level of the backend of the WEWW application

Machine learning/regression models

First linear regression models were created for each combination of variables that the user entered and subsequently, regression equations were calculated. Linear regression modelling is considered a very basic form of machine learning (ML). It is a process where a computer (machine) learns about a dataset and can predict responses, given specific variables[270] and was initially chosen for this project as this process is well established at prediction in clinical care.[271]

One could argue that the use of the term ML to represent simple linear-regression equation is not necessarily a model, yet literature often classifies this as a machine-learning.[272] The Apple documentation[270, 273] refers to the development of a linear regression equation leading to a prediction as an ML model, and for this reason, both regression equation and ML models will be examined. Furthermore, incorporating this early in application design as an ML model allows modularity making future development, including the use of more complex ML models in post PhD development.

ML can be broken down into three types of learning: supervised learning, where the user provides a dataset containing input and output variables; unsupervised learning, where only input data is provided; and reinforcement learning, where the environment provides information regarding both input and output data.[270] The WEWW application is designed using supervised machine learning where the initial dataset from Statistics NZ[63] contained the height, age, gender, ethnicity and weight variables for ML.

As with any software design for a mobile device, specific considerations in the design process are required. For example, the size of the model, working memory and processing speed. With these considerations, along with simplicity in mind, linear-regression modelling was selected, as even though the dataset for the modelling was large, the data itself is considered simple (paired data).[274, 275] The simplicity of the data also allowed for a less complicated prediction model, and less use of memory.[270] The accuracy of the regression prediction model developed will be tested for fit in the Testing Chapter. If a change in the methods of the regression models or introduction of a more advanced ML model is required, this will form a part of the post-doctoral research.

Dataset for linear-regression modelling

The dataset for the linear-regression modelling originated from the Statistics New Zealand – National Health Survey conducted between 2011 and 2016.[63] The initial data contained 23,217 sets of data including age, weight, height, ethnicity and gender for NZ children. The data was then cleaned using the method shown in Figure 62, leaving 17,054 sets of data. On visual inspection of the data, several records recorded a given child's weight as being under 1 kg with a height that was not proportional (e.g., 1.6 m).

Children over 14 years and under the age of 2 years were excluded. To allow comparison with other research around weight estimation in paediatric resuscitation children under the age of two were removed from the dataset, leaving a total of 16,890 records.

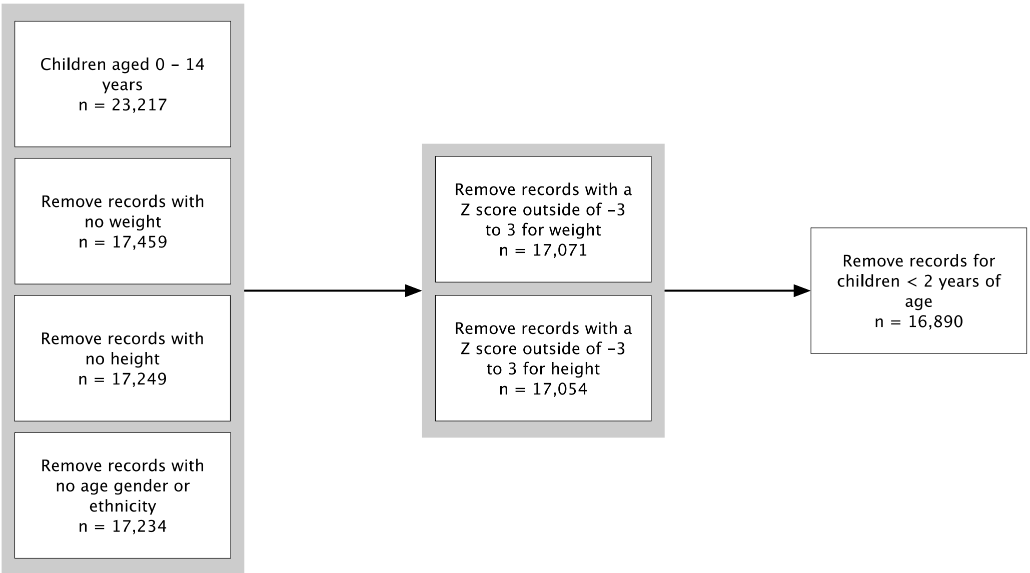


Figure 62 - Cleaning of the data and removal of outliers based on a z score of < -3 or > 3

Ten sets of ambiguous data were removed where height or weight did not match age (for example) a nine-year-old who is 49 cm in height, leaving 16,880 records.

Data quality was managed by NZ Ministry of Health staff, who ensured data collection quality was maintained and any data was checked and edited by the before analysis[276] Data that was not clear was returned to the interviewer for clarification prior to entry into the database. Even with these checks in place some data was still missing and errors were apparent in the final dataset (Table 24) that the researcher received leading to the removal of this data using the process described above.

Table 24 - Data Quality

Error	**n**	**Ratio**	**%**
Data Missing (height, weight)	5758	5758:23217	24.8
Empty Values (demographic values)	45	15:7739	0.001
Removed or Unwanted Data	164	164:23217	0.007
Data Error (ambiguous Data)	10	10:23217	0.0004

Examination of the dataset revealed the following demographic characteristics (Table 25).

Table 25 - Demographic Statistics

Age in years	**n**	**%**
2	1335	7.9
3	1388	8.2
4	1419	8.4
5	1309	7.8
6	1360	8.1
7	1276	7.6
8	1255	7.4
9	1214	7.2
10	1183	7
11	1267	7.5
12	1277	7.6
13	1287	7.6
14	1310	7.8
Gender	**n**	**%**
Male	8695	51.5
Female	8185	48.5
Ethnicity	**n**	**%**
Maori	6114	36.2
Pacific	1621	9.6
Asian	1661	9.8
Other	7484	44.3

Table 26 indicates near-normal skewness of height, gender and age, while the skew of weight is skewed to the right, which shows that there are far more lighter children in the sample and means that the models/equations could be less accurate for heavier children. Decreased accuracy for older and heavier children is common and a known limitation of existing weight estimation methods.[13, 19, 27, 277] This could have been influenced by the removal of children under the age of two from the dataset to allow for comparison with other studies. However, practices worldwide where weight estimation dependant on age or height is generally not recommended for children under two years or over 14 years.[27] While skewness remains < 1, which is considered acceptable,[278] the skewness and subsequent performance of weight estimates for heavier children need to be listed as a limitation of this study. For kurtosis, with samples over 300 sets of data are acceptable at between -2 and 2.[278] While kurtosis is within these parameters for all of the variables, gender is close to -2 which is most likely to be because gender is coded a dummy variable where 0 = male and 1 = female which is binary. The peaked nature of Figure 64 on the left indicates more measurements of weight in lighter children and means that weight estimation for heavier children will most likely be less accurate than lighter children. Standard Error (SE) is minimal for both skewness and kurtosis. Figure 63, Figure 64 and

Table 26 illustrate this dataset meets skewness and kurtosis requirements listed above and therefore, no transformation of data was performed.

Table 26 - Skewness and kurtosis as a guide to normal distribution

					Mean		Skewness		Kurtosis	
	n	**Min**	**Max.**	**Mean**	**SE**	**SD**		**SE**		**SE**
weight	16880	9.30	92.20	34.89	0.14	17.82	0.85	0.02	-0.07	0.04
height	16880	59.30	188.60	130.58	0.19	24.37	-0.03	0.02	-1.04	0.04
age	16880	2.00	14.00	7.90	0.03	3.78	0.05	0.02	-1.24	0.04
gender	16880	0.00	1.00	0.48	0.00	0.50	0.06	0.02	-2.00	0.04

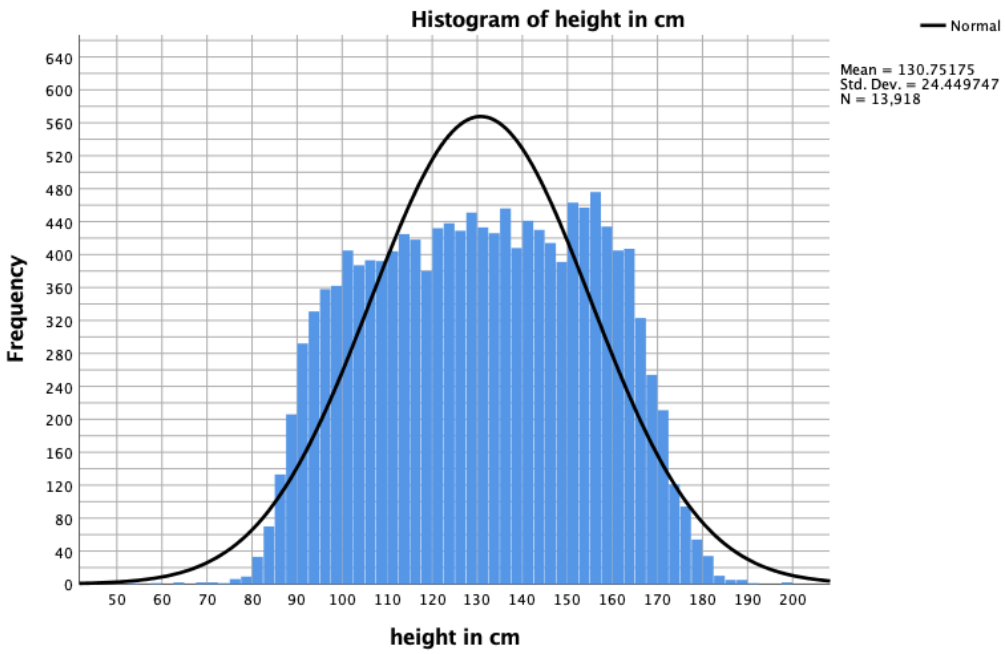


Figure 63 - Distribution of height in the Statistics NZ Dataset[63]

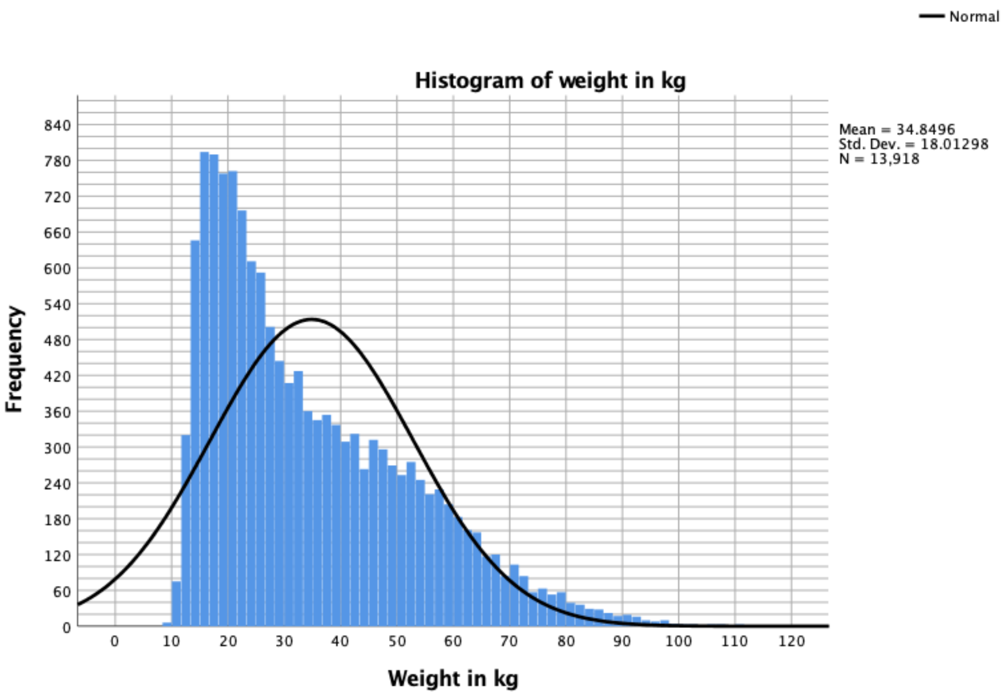


Figure 64 - Distribution of weight in the Statistics NZ dataset

Regression model development

The dataset was randomly split into two subsets using SPSS, *regression dataset* (n = 8467) used to create regression equation/model, and *test dataset* (n = 8413) used to test the accuracy of the regression equation/model.

Linear regression modelling was performed for the whole dataset without ethnicity included along with one each ethnic group giving five regression models and subsequent equations. Previous research indicates that alongside age and height, ethnicity influences weight estimates,[14, 16, 17] therefore one model was made for each ethnicity so that weighting is not given to any ethnic group thus removing the risk of bias from ethnicity coding. As height is the base measure that we will measure within the WEWW application, all estimates will be derived from this with the hope of becoming more accurate with the addition of other variables such as gender and age.

Linear-regression was achieved using a forward stepwise model with AAC information criterion with 95% CI in SPSS (version 24). This meant that the effect with p-values <0.05 were included and those over were excluded, as were outliers in the height category.

The linear regression models were then incorporated as coreML models into the WEWW application, which automatically selects the appropriate model based on the data supplied by the user. It is worth noting that, at the time, these were created using *coreML 2* and the ability to generate machine learning models that were required to ensure ease of later development was not yet fully available for Apple developers.

One problem encountered was that initial models were developed using *SPSS* (version 24),[279] which was unable to be exported in a format which the Apple Inc.[262] software XCode,[212] could import. Xcode[212] is an integrated development environment that allows for the programming and compiling of applications created for Apple devices; however, interoperability with non-apple platforms and devices is challenging. Therefore, Apple Inc.[262] suggests the use of the *scikit-learn*[280] module in *Python*[267] (version 2.7) to regenerate these models as ML models using the same criteria and subsequently export them in a format that could be utilised in developing for the Apple iOS platform. The *Python*[267] script used to create the regression models from the Statistics NZ cleaned dataset[63] can be seen in section 10.6.12 - Appendix F – Python script for conversion of Linear-regression models to coreML models.

Regression equation development

To formulate this, the mean, SD and Confidence Intervals of 95% were utilised. Linear-regression was run using weight (dependant Variable) and independent variables age, gender and height. It is also worth noting that *SPSS* (version 24)[279] uses a large Cook's distance to automatically remove outliers using automatic linear-regression modelling to improve the accuracy of the regression model while making the modelling process more robust. Results of these tests were applied to **Error! Reference source not found.** where B represents the unstandardized beta coefficients for each variable, height (cm), age (years) and sex (0 = male, 1 = female).

Equation 9 – Predicted weight linear regression equation

$$weight = Constant + (Height\ B \times Height) + (Age\ B \times Age) + (Gender\ B \times Gender)$$

or

$$weight = \beta_0 + (\beta_1 \times Height) + (\beta_2 \times Age) + (\beta_3 \times Gender)$$

Table 27 shows the equations which were derived.

Table 27 - Regression equations for dependent variable weight

Group	Equation to predict weight	Adjusted R^2
All	$-42.974 + (0.592 \times \text{Height}) + (0.413 \times \text{Age}) + (0.425 \times Gender)$	0.803
Maori	$-45.920 + (0.586 \times \text{Height}) + (0.658 \times \text{Age}) + (0.422 \times Gender)$	0.802
Pacific	$-59.997 + (0.753 \times \text{Height}) + (-0.024 \times \text{Age}) + (0.203 \times Gender)$	0.816
Asian	$-44.922 + (0.596 \times \text{Height}) + (0.039 \times \text{Age}) + (-0.296 \times Gender)$	0.802
Other	$-41.497 + (0.541 \times \text{Height}) + (0.476 \times \text{Age}) + (0.841 \times Gender)$	0.822

Photogrammetry inside the WEWW application

The photogrammetry of the WEWW application was predominantly completed using *ARKit*[265], which was released by Apple in 2017. The photogrammetry occurs in real time via the back camera of the iPhone using AR to determine points in the user's three-dimensional (3D) or real-world environment by overlaying a cross onto the device screen in a video (Figure

65). The photogrammetry is initiated by the class called *MeasureARViewController* class in section 10.6.5 in Appendix F – Code of this thesis.

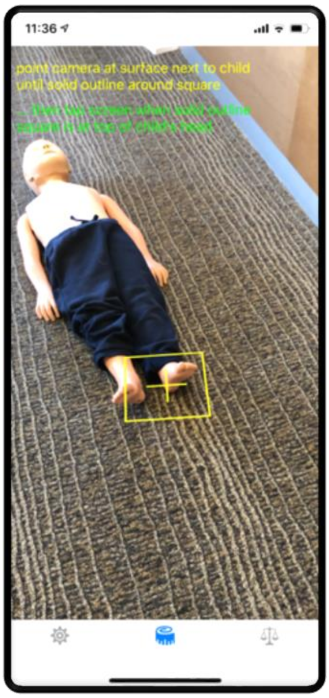


Figure 65 - using ARKit[265] to overlay a cross onto the environment to assist with measurement

When the *MeasureARViewController* is run, some setup is required to allow the translation of what the user sees on the screen to data that can be utilised by regression models.

First, the tracking configuration is set configured by detecting the horizontal plane that the child is situated on. As a part of this process, the *ARWorldTrackingConfiguration*,[281] the WEWW application detects the position of the mobile device in space and relation to horizontal surfaces, placing *ARPlaneAnchor*s[282] on each surface that is detected. The configuration process then creates a coordinate system that represents the three-dimensional view in a two-dimensional manner.[266] In other words, the *ARWorldTrackingConfiguration*[281] class is the bridge between the three-dimensional world and the two-dimensional world seen on the mobile device. The user points the camera at the horizontal plane (e.g. the floor) and when the square outline becomes solid yellow, the horizontal plane is detected and all measurement is relative to this plane. The user needs to point the cross at the heel and then tap the screen and then head and tap, the order of these two actions do not matter as we are measuring the distance in relation to the horizontal plane. The messages on the screen prompt the user with what to do. For example, “point the camera at the floor next to the child”, “point the cross at their feet and tap the screen”.

The child is measured by user input. The user indicates the top of his or her head and bottom of the heel by tapping on the phone screen. A *focusSquare* in the form of an *SCNNode* shows the user a square with a cross-hair at the centre to ensure accuracy when indicating the head and heel. The *focusSquare* class is adapted from the example code (distributed by Apple Inc.[283]

that uses its position to place three-dimensional objects into an environment on surfaces. The *focusSquare* is an overlay using augmented reality, which positions itself based on the movement of the mobile device running the WEWW application. The moving *focusSquare* allows the user to move around in the three-dimensional environment while the data is transformed into a two-dimensional coordinate system. This will be particularly useful in the resuscitation environment, which is often busy, and the user of the WEWW application may need to move around others for measurement.

The position of the *focusSquare* can be set using the *updateFocusSquare* function and is based on the current camera frame information (Code Snippet 17). The primary purpose of this function is to ensure the *focusSquare* is initially shown in the middle of the screen and initiates updates of its location based on each analysed video frame.

Code Snippet 17 - *updateFocusSquare* function in the *MeasureARViewController* class

```
   func updateFocusSquare() {
        focusSquare.unhide()

        // start with focus square in the middle of the screen
        let (worldPosition, planeAnchor, _) =
worldPositionFromScreenPosition(view.center, objectPos: focusSquare.position)

        if let worldPosition = worldPosition {
          focusSquare.update(for: worldPosition, planeAnchor: planeAnchor,
camera: sceneView.session.currentFrame?.camera)
        }
      }
```

A further function of the *focusSquare* class is named *update* which is called from the *updateFocusSquare* function but can also be called independently from the update function (Code Snippet 17). This class sets the position of the focus square on the plane and initiates the translation of that position into coordinates in relation to the two-dimensional frame being examined by the mobile device.

Code Snippet 18 - *update* function from the *focusSquare* class

```
   func update(for position: SCNVector3, planeAnchor: ARPlaneAnchor?, camera:
ARCamera?) {
        lastPosition = position
        // close the square if the plane anchor has not been
        // visited update the position and insert it into
        // visited planes otherwise keep the square open
        if let anchor = planeAnchor {
          close(flash: !anchorsOfVisitedPlanes.contains(anchor))
          lastPositionOnPlane = position
          anchorsOfVisitedPlanes.insert(anchor)
        } else {
          open()
        }
        updateTransform(for: position, camera: camera)
      }
```

The camera position is corrected using the *updateTransform* function (

Code Snippet 19) to ensure that any rotation on the y-axis is not translated to the user screen. This way the *focusSquare* stays on the first horizontal plane located when overlaid on the screen of the mobile device. This is done to ensure that the plane is not automatically changed during use of the WEWW application.

Code Snippet 19 - *updateTransform* function in the *focusSquare* class

```
  private func updateTransform(for position: SCNVector3, camera: ARCamera?) {
      // add to list of recent positions
      recentFocusSquarePositions.append(position)

      // remove anything older than the last 8 positions
      recentFocusSquarePositions.keepLast(8)

      // move to average of recent positions to avoid jitter
      if let average = recentFocusSquarePositions.average {
        self.position = average
        self.setUniformScale(scaleBasedOnDistance(camera: camera))
      }

      // Correct y rotation of camera square pitch, yaw, roll
      if let camera = camera {
        let tilt = abs(camera.eulerAngles.x)
        let threshold1: Float = Float.pi / 2 * 0.65
        let threshold2: Float = Float.pi / 2 * 0.75
        let yaw = atan2f(camera.transform.columns.0.x,
camera.transform.columns.1.x)
        var angle: Float = 0

        switch tilt {
        case 0..<threshold1:
          angle = camera.eulerAngles.y
        case threshold1..<threshold2:
          let relativeInRange = abs((tilt - threshold1) / (threshold2 -
threshold1))
          let normalizedY = normalize(camera.eulerAngles.y,
forMinimalRotationTo: yaw)
          angle = normalizedY * (1 - relativeInRange) + yaw * relativeInRange
        default:
          angle = yaw
        }
        self.rotation = SCNVector4Make(0, 1, 0, angle)
      }
    }
```

A *tapGestureRecognizer* is created to recognise user input. The *motionManager* function then detects motion and records the position of the phone (pitch, yaw and roll) every 0.1 seconds. If a user taps the screen, the position they touch is recorded using x, y, z coordinate configuration in relation to the horizontal plane detected earlier. A red sphere (*SCNNode*[268]) is drawn on the horizontal plane at this point. On the second user tap, a second sphere is placed on the plane, which triggers the calculation of the distance between the two spheres that represent the length of the child. The function *worldPositionFromScreenPosition* (Code Smippet 20*)* handles the user input (screen taps) and initiates the translation from the screen (two-dimensional representation) to the real world (three-dimensional environment).

Code Snippet 20 - worldPositionFromScreenPosition function in MeasureARViewController

```
   func worldPositionFromScreenPosition(_ position: CGPoint,objectPos: 
SCNVector3?, infinitePlane: Bool = false) -> (position: SCNVector3?, 
planeAnchor: ARPlaneAnchor?, hitAPlane: Bool) {
       // set the plane hit test results to the position on the 
       // current plane
       let planeHitTestResults = sceneView.hitTest(position, types: 
.existingPlaneUsingExtent)

       // if this is the first result update the plane anchor
       // to match the place on the screen tapped
       if let result = planeHitTestResults.first {

         // set hit test position to be the plane anchor or
         // center of the focus square
         let planeHitTestPosition = 
SCNVector3.positionFromTransform(result.worldTransform)
         let planeAnchor = result.anchor
         return (planeHitTestPosition, planeAnchor as? ARPlaneAnchor, true)
       }

       // If this isn't the first hit test tap check the
       // quality of the hit test
       var featureHitTestPosition: SCNVector3?
       var highQualityFeatureHitTestResult = false

       // Test the quality of the hit test
       let highQualityfeatureHitTestResults = 
sceneView.hitTestWithFeatures(position, coneOpeningAngleInDegrees: 18, 
minDistance: 0.2, maxDistance: 2.0)

       // If this is empty / not of high quality then
       if !highQualityfeatureHitTestResults.isEmpty {
         let result = highQualityfeatureHitTestResults[0]
         featureHitTestPosition = result.position
         highQualityFeatureHitTestResult = true
       }
       // Ignore the real-world hit test if it is not good
       // quality and use the existing information
       // about the horizontal plane
       if (infinitePlane && dragOnInfinitePlanesEnabled) || 
!highQualityFeatureHitTestResult {
         let pointOnPlane = objectPos ?? SCNVector3Zero
         let pointOnInfinitePlane = 
sceneView.hitTestWithInfiniteHorizontalPlane(position, pointOnPlane)
         if pointOnInfinitePlane != nil {
           return (pointOnInfinitePlane, nil, true)
         }
       }

       // Return the current hit test if the quality checking
       // was skipped
       if highQualityFeatureHitTestResult {
         return (featureHitTestPosition, nil, false)
       }

       // If no quality gets the hit test again.
       let unfilteredFeatureHitTestResults = 
sceneView.hitTestWithFeatures(position, coneOpeningAngleInDegrees: 180)
       if !unfilteredFeatureHitTestResults.isEmpty {
         let result = unfilteredFeatureHitTestResults[0]
         return (result.position, nil, false)
       }
       return (nil, nil, false)
     }
```

To understand the translation between the real-world and two-dimensional coordinates, an overview of the functionality of an *SCNNode*[268] is required. Each time the user taps, a red sphere is created on the screen. The sphere represents an *SCNNode*[268] that stores its position information in an *SCNVector3*[284] (a three-component vector) as coordinates using the x, y, z coordinate system. The *SCNVector3* class is extended in the WEWW application (Code Snippet 21) to provide further functionality when it is instantiated.

Code Snippet 21 - SCNVector3 extension

```
  extension SCNVector3 {

    // use the vector to set the position
    init(_ vec: vector_float3) {
      self.init()
      self.x = vec.x
      self.y = vec.y
      self.z = vec.z
    }

    func length() -> Float {
      return sqrtf(x * x + y * y + z * z)
    }

    // return the difference SCNodes which or length of the child
    func distanceFromPos(pos: SCNVector3) -> Float {
      let diff = SCNVector3(self.x - pos.x, self.y - pos.y, self.z - pos.z);
      return diff.length()
    }
    mutating func setLength(_ length: Float) {
      self.normalize()
      self *= length
    }
    mutating func setMaximumLength(_ maxLength: Float) {
      if self.length() <= maxLength {
        return
      } else {
        self.normalize()
        self *= maxLength
      }
    }
    mutating func normalize() {
      self = self.normalized()
    }
    func normalized() -> SCNVector3 {
      if self.length() == 0 {
        return self
      }
      return self / self.length()
    }

    // Transform the position returning a new vector
    static func positionFromTransform(_ transform: matrix_float4x4) ->
SCNVector3 {
      return SCNVector3Make(transform.columns.3.x, transform.columns.3.y,
transform.columns.3.z)
    }
    func friendlyString() -> String {
      return "(\(String(format: "%.2f", x)), \(String(format: "%.2f", y)),
\(String(format: "%.2f", z)))"
    }
    func dot(_ vec: SCNVector3) -> Float {
      return (self.x * vec.x) + (self.y * vec.y) + (self.z * vec.z)
    }

    // coordinates center cross
    func cross(_ vec: SCNVector3) -> SCNVector3 {
      return SCNVector3(self.y * vec.z - self.z * vec.y, self.z * vec.x -
self.x * vec.z, self.x * vec.y - self.y * vec.x)
    }
```

```
    }
```

Code to determine the length between two sphere's is shown in Code Snippet 22

Code Snippet 22 - Determining length between spheres

```
   let vector = startNode.position - endNode.position
   let formatter = NumberFormatter()
   formatter.numberStyle = .decimal
   formatter.roundingMode = .ceiling
   formatter.maximumFractionDigits = 2

   // get the distance between the nodes in m and cm and put in
   // static variables
   staticVariables.lengthInM = Double(truncating: NSNumber(value:
vector.length()))
   staticVariables.heightInCM = staticVariables.lengthInM*100
```

6.3 Chapter Summary

This chapter has presented the development of the WEWW application prototype up until the commencement of user testing. Firstly the purpose was revisited, and this led to an explanation interrelating the this with design considerations (mobile context, deployment environment, information privacy and security, regulation plus users and their context) required for the development of the WEWW application.

The rationale for design decisions and simplification of the weight estimation workflow have been included along with the design of the regression models and regression equations that underpin the prediction of weight in the WEWW application.

With technology advancing, new libraries were released to manage augmented reality (AR) when development began. These automatically addressed many of the issues investigated in Chapter Four; therefore, a switch to using the new libraries rather than programming solutions were implemented. Furthermore the user workflows were streamlined and GUI tweaked to provide a more streamlined look and feel.

7 Chapter Seven - Testing

7.1 Introduction

This chapter outlines the processes of alpha, accuracy and user testing along with user acceptability of the Weight Estimation without Waiting (WEWW) application. The chapter presents the research question, design, data collection, methods and results in their entirety for each of the research questions posed while testing the WEWW application.

Firstly, the testing design is introduced, followed by a recap of the research questions. Following this, research questions will be addressed using traditional scientific experiment headings of Research Questions, Methods, Data Collection, Data Analysis and Results. Interpretation of results will occur throughout Chapter Eight – Discussion. As with previous chapters, regression models are referred to as regression model or ML model and are used to predict weight in the WEWW application complied on an iPhone. While regression equations if these notations are followed by a subscript $_c$, this denotes the use of the iPhone camera to measure length while a subscript $_s$ denotes the use of the stadiometer.

7.2 Methods

Testing of the WEWW application is in three distinct phases. The first phase is accuracy testing; this involves the examination of the regression model fit. After this weight estimates calculated for an existing Statistics New Zealand (NZ) dataset[63] using endorsed weight estimation methods New Zealand Resuscitation Council (NZRC)[18] and St John NZ[36] are compared with estimates from the regression equations/models designed in this study. A preliminary investigation of the sources and distribution of error is completed, including analysis of technology-induced error associated with camera measurement.

Alpha testing occurs next, which consists of exploratory and functional testing of the WEWW application, along with the evaluation of the WEWW application against the acceptance criteria.

The last type of testing is user testing, which investigates the usability through observation and user verbal responses, and user's acceptance of the WEWW application using an adaptation of the Technology Acceptance Model (TAM).[285, 286]

An overview of the testing design is shown in Figure 66 with each method of testing described in more detail later in this chapter.

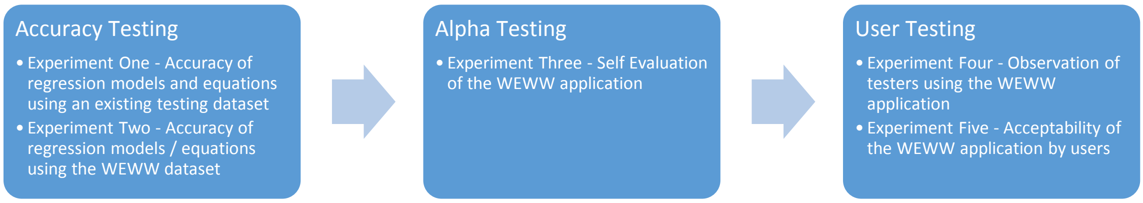


Figure 66 – Overview of testing design

7.2.1 Research questions

Testing of the WEWW application occurs through a series of experiments, each of which answers several research questions. An overview of the relationship between experiments and research questions can be seen in Figure 67.

Accuracy Testing	Alpha Testing	User Testing
• **Experiment One - Accuracy of regression models and equation using existing data** • RQ1: How good is the fit of the regression models? • RQ2: How accurate are weight estimates using regression model/equation compared with existing estimation methods? • **Experiment Two - Accuracy of regression models, equation using the WEWW dataset** • RQ3: How accurate are weight estimates using camera height with regression model/equation compared with existing estimation methods? • RQ4: How accurate are weight estimates using actual height with regression model/equation compared with estimation methods?	• **Experiment Three - Self Evaluation of the WEWW application** • RQ5: Identify and correct functional testing issues • RQ6: Identify and correct exploratory testing issues • RQ7: Does the WEWW application meet the Acceptance Criteria?	• **Experiment Four - Observation of testers using the WEWW application** • RQ8: What do the participants thought processes while using the WEWW application? • RQ9: How did the participants interact with the WEWW application? • **Experiment Five - Acceptability of the WEWW application by users** • RQ10: Do users believe the WEWW application is useful in practice? • RQ11: Do users intend to use the WEWW application in their practice? • RQ12: Is the WEWW application easy to use? • RQ13: What do users perceive as the risk of harm or privacy breach in using WEWW? • RQ14: What are users' attitude towards the WEWW application?

Figure 67 - Experiments and related research questions

7.2.2 Consultation

Consultation around the design and data collection for this research occurred via the Mātauranga Māori Committee (MMC) from the School of Clinical Sciences at Auckland University of Technology in 2018. The committee made minor recommendations around the research process, which have been incorporated into the design of this study. They later issued a letter verifying Māori Consultation (section **Error! Reference source not found. Error! Reference source not found.**).

7.2.3 Ethics approval

Functional testing included measuring children aged between 1 and 14 years, while user testing included healthcare professionals testing the WEWW application in a simulated environment. As both components of testing required public engagement, ethics approval was gained from the Auckland University of Technology Ethics Committee (AUTEC).

Ethics approval for measurement of children and was granted by the Auckland University of Technology Ethics Committee with the ethics approval number 18/213 (**Error! Reference source not found.**). Information sheets, along with parental consent and child assent forms, can be seen in **Error! Reference source not found.**.

7.3 Accuracy testing

Accuracy testing gives an overview of the performance of the WEWW application against existing methods of weight estimation. Traditional research terminology and processes will be utilised, along with descriptive statistics for reporting.

7.3.1 Experiment One

Accuracy of regression models/equations that were derived from the Statistics NZ dataset[63] was compared with weight estimates calculated using the NZRC and St John methods.

Experiment one includes research questions.

- RQ1: How good is the fit of the regression models?
- RQ2: How accurate are weight estimates using regression model/equation compared with existing estimation methods?

7.3.2 Research Question One

Methods

Research question one addresses the fit of the regression models/equations derived during the development of the WEWW application.

Data Collection

Data collection was achieved using data in an existing dataset that is described in detail in section 6.2.8, which discusses the method used to create the regression models and derive the regression equations.

Data Analysis

Data analysis was completed using *SPSS* (version 24).[279] Analysis included an examination of the dataset using descriptive statistics including demographic characteristics, with interactions between variables were checked firstly using Kendall's tau b as the assumptions for this were met by the dataset.

According to Berk,[274] the best way to evaluate the fit of a regression equation/model is to use both a quantitative measure, such as the adjusted R^2, and subject expertise. The adjusted R^2 gives a percentage representing accuracy, with the subject or clinician expertise considered throughout the discussion chapter of this thesis.

Due to the inability to import an existing regression equation/model from within the WEWW application (*coreML)* into statistical analysis software the fit of regression equation/model was tested using models created both the *Python*[267] and *SPSS* (version 24)[279] from the same dataset (discussed in detail within Section 6.2.8 on page 114).

Results

Demographics, normality and distribution of the Statistics NZ dataset[63] used to generate the regression equation/model are reported previously in section 6.2.8 along with the methods used to develop the equations.

As expected, a very strong positive correlation was apparent between weight and height (τ_b = 0.806, p = 0.01) and age and height (τ_b = 0.840, p = 0.01). A strong positive correlation was evident between age and weight (τ_b = 0.756, p = <0.001). Literature has shown a similar strong correlation between age and weight, height and weight and existing weight estimation methods are generally based on either height or age.[13, 14, 16, 19, 27] A weak, very weak or marginal correlations were shown between all other variables and can be seen in Table 28.

Table 28 - Kendall's tau b correlation coefficients used to indicate relationships between variables.

		Age	**Gender**	**Ethnicity**	**Weight**	**Height**
	n	8467	8467	8467	8467	8467
Age	τ_b	1	$-.021^{*}$	$.018^{*}$	$.756^{**}$	$.840^{**}$
	Sig. (2-tailed)	.	0.02	0.042	0.000	0.000
Gender	τ_b	$-.021^{*}$	1	0.02	$-.030^{**}$	$-.038^{**}$
	Sig. (2-tailed)	0.02	.	0.055	0.001	0.000
Ethnicity	τ_b	$.018^{*}$	0.02	1	$-.045^{**}$	-0.004
	Sig. (2-tailed)	0.042	0.055	.	0.000	0.64
Weight	τ_b	$.756^{**}$	$-.030^{**}$	$-.045^{**}$	1	$.806^{**}$
	Sig. (2-tailed)	0.000	0.001	0.000	.	0.000
Height	τ_b	$.840^{**}$	$-.038^{**}$	-0.004	$.806^{**}$	1
	Sig. (2-tailed)	0.000	0.000	0.64	0.000	.

τb = correlation coefficient using Kendall's tau b, ** = significant at 0.01, * = significant at 0.05

Table 29 Illustrates the fit of the regression equations created in SPSS. It is worth noting that at creation the adjusted R^2 value indicates that all equations have 80% or above accuracy.

Table 29 – Regression equations derived from the dataset for regression modelling with the adjusted R^2 illustrating the accuracy of models/equations.

Group	Equation to predict weight	Adjusted R^2
All	$-42.974 + (0.592 \times \text{Height}) + (0.413 \times \text{Age}) + (0.425 \times Gender)$	0.803
Maori	$-45.920 + (0.586 \times \text{Height}) + (0.658 \times \text{Age}) + (0.422 \times Gender)$	0.802
Pacific	$-59.997 + (0.753 \times \text{Height}) + (-0.024 \times \text{Age}) + (0.203 \times Gender)$	0.816
Asian	$-44.922 + (0.596 \times \text{Height}) + (0.039 \times \text{Age}) + (-0.296 \times Gender)$	0.802
Other	$-41.497 + (0.541 \times \text{Height}) + (0.476 \times \text{Age}) + (0.841 \times Gender)$	0.822

7.3.3 Research Question Two

Methods

Accuracy of the regression equation/model weight estimates when compared with endorsed weight estimations (NZRC and St John) is achieved by determining the limits of agreement, mean percent error (MPE) and the percentage of children's weights within a given percent of actual weight. Figure 68 illustrates the process followed for testing research question two.

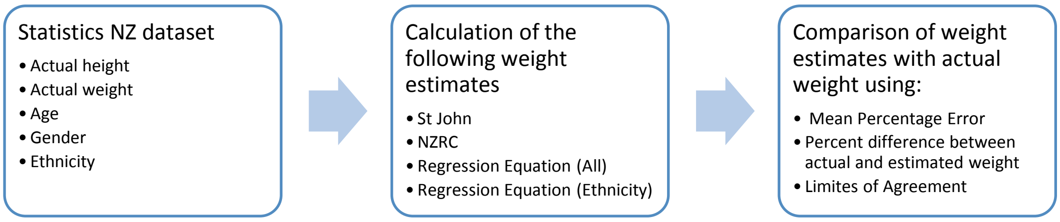


Figure 68 – The process of comparing weight estimation methods using the existing Statistics NZ dataset

Data Collection

Data collection is primarily in the form of calculations based on an existing dataset provided by Statistics NZ[63] that is described in detail in section 0.

Firstly the following weight estimates were calculated using variables available in the dataset (age, gender, ethnicity and height):

- Regression equation/model (All) weight estimate
- Regression equation/model (Ethnicity) weight estimate
- St John weight estimate
- NZRC weight estimate

Data Analysis

To compare weight estimates calculation of the Mean Percentage Error (MPE), Limits of Agreement (LoA) and mean percentage of weights within a given percentage (10%, 20% and 30%) using the variables actual weight along with the four weight estimates listed above. At this point, it is worth noting that a negative MPE represents an overestimation of weight while a positive MPE represents an underestimation of weight when analysing the results.

Equation 10 - Mean Percentage Error (MPE) using estimated (E) and actual weight (M).

$$MPE = \frac{M - E}{M} \times 100$$

Many studies report weight estimation using the limits of agreement presented as Bland Altman Plots.[17, 35, 68, 287-289] Therefore an analysis using limits of agreement was undertaken by calculating the difference between each actual weight and weight estimate. A single sample t-test was run to determine SD and upper and lower limits of the agreement at 95% CI (Equation 11).

Equation 11 - Calculation of upper and lower levels of agreement

$$Upper\ CI = (SD\ \times 1.96) + mean$$

$$Lower\ CI = mean - (SD \times 1.96)$$

Bland-Altman[290] plots were then generated, showing limits of agreement for the regression equation/model weight estimate, St John weight estimate and NZRC weight estimate when compared with actual weight.

The third way that literature often presents comparison of a weight estimate with actual weight is to express this is by indicating whether the weight estimate falls within 10%, 20% or 30% of the measured weight of a child.[19, 165]

This was achieved by calculating the difference between each weight estimate and actual weight as a percentage and determining the proportion of estimates within 10%, 20% or 30% of actual weight for each of the weight estimation methods.

Results

Accuracy of weight estimates was analysed in three different ways because reporting varies throughout the literature, making comparisons challenging. Therefore, the three most common statistical reporting methods are used to report results:

- Mean Percentage Error (MPE)
- Limits of Agreement (Bland Altman Plots)[290]
- Percentage of weight estimates within a given percent of actual weight.

Results shown in bold in tables represent the most accurate methods of weight estimation. Table 30 shows the MPE, SD of weight estimates using regression equations derived from all participants (All) or derived by ethnicity (Ethnicity) for comparison with the St John and NZRC weight estimates for children included in the Statistics NZ dataset.[63] The regression equation based on ethnicity outperforms all other methods of weight estimation for the test dataset. The next most accurate weight estimation technique is the regression equation without the ethnicity included, where the mean error is increased by over 11%. This illustrates that adding ethnicity in calculations can improve the accuracy of weight estimates using regression modelling. The use of regression equations as opposed to existing weight estimation methods reduces the mean error by at least 5%. However, it is interesting to note that the SD is lower for existing methods of weight estimation and further post-doctoral work will investigate alternative models which may improve the SD of the regression models/equations.

Table 30 – Application of NZ derived and endorsed weight estimation techniques to a statistics NZ dataset[63]

	n	**MPE**	**SD**
All	8413	-12.4	23.7
Ethnicity	8413	**-1.1**	23.3
NZRC	8413	21.6	**16.7**
St John	8413	18.9	16.9

MPE = Mean Percentage Error, SD = Standard Deviation

Table 31 shows the relationship between MPE and age in years. What is evident is that the MPE of models based on ethnicity generally outperform the other methods of weight estimation. The St John formula and NZRC typically less accurate as children get older (and heavier) whereas the regression models/equations are generally less accurate for children aged 5 – 10 years. Interestingly, ethnicity makes estimates less accurate in regression models/comparisons for children less than four years, while including this for children over four years brings more accuracy. Future research could consist of an analysis of growth pattern, activity levels and school curriculum, which may influence adiposity[70] and therefore, weight.

Table 31 - Relationship of age and mean percentage error of each estimation method

Age in years	**MPE All**	**MPE Ethnicity**	**MPE St John**	**MPE NZRC**
2	16.0	36.4	16.6	16.6
3	-2.2	15.4	15.4	15.4
4	-14.7	1.0	15.3	15.3
5	-22.5	-8.6	16.5	16.5
6	-27.2	-14.4	17.1	17.1
7	-26.1	-14.9	19.4	19.4
8	-23.7	-13.4	22.4	22.4
9	-20.3	-11.4	26.0	26.0
10	-17.6	-9.4	23.1	15.4
11	-12.2	-4.9	25.8	18.4
12	-7.0	-0.6	28.7	21.6
13	-5.2	1.1	28.3	21.2
14	-2.4	3.7	28.7	21.5

Distribution of MPE by ethnicity is shown in Figure 69 (Maori), Figure 70 (Pacific), Figure 71 (Asian), Figure 72 (Other ethnicities). Near normal distribution of MPE is achieved for Maori children using all methods of weight estimation. The distribution of error is less clear cut for other ethnicities. For example, the exclusion of ethnicity in the regression model/equation leads to an underestimation of weight for pacific children. In contrast, the opposite applies to Asian children, where weight is generally overestimated. Furthermore, St John and NZRC give a more significant underestimation of weight than methods of estimation in this study.

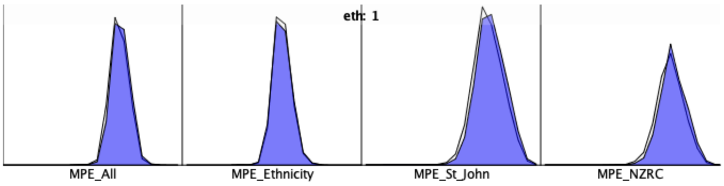


Figure 69 - Distribution of MPE for Maori children.

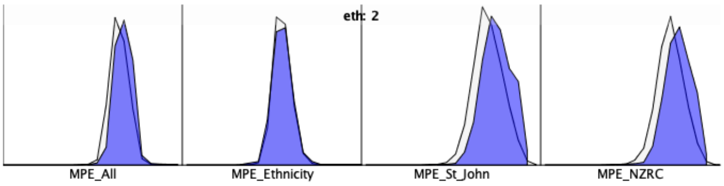


Figure 70 - Distribution of MPE for Pacific Children

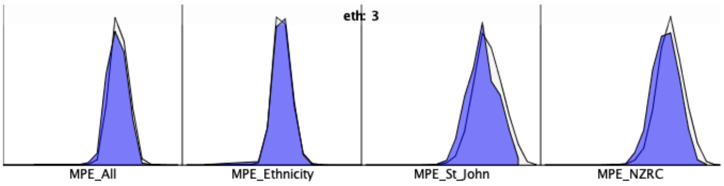


Figure 71 - Distribution of MPE for Asian Children

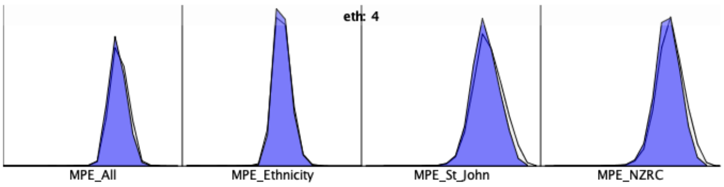


Figure 72 - Distribution of MPE for children of other ethnicities

Figure 73 shows the distribution of MPE grouped by age. For children aged 2 to 3 years, the errors in regression models tend to overestimate the weight of children, whereas the NZRC and St John formulae tend to underestimate the weight of children. Both regression models/equations are more peaked than St John and NZRC estimation methods which are more apparent for younger children and at the age of 9 years, the errors are relatively normally distributed. The most obvious observation was that the distribution of errors for children aged 10 – 14 years was further from normal for existing weight estimation methods for the existing weight estimation techniques. In post-doctoral work, determining data transformation required to normalise the distribution of errors will be included.

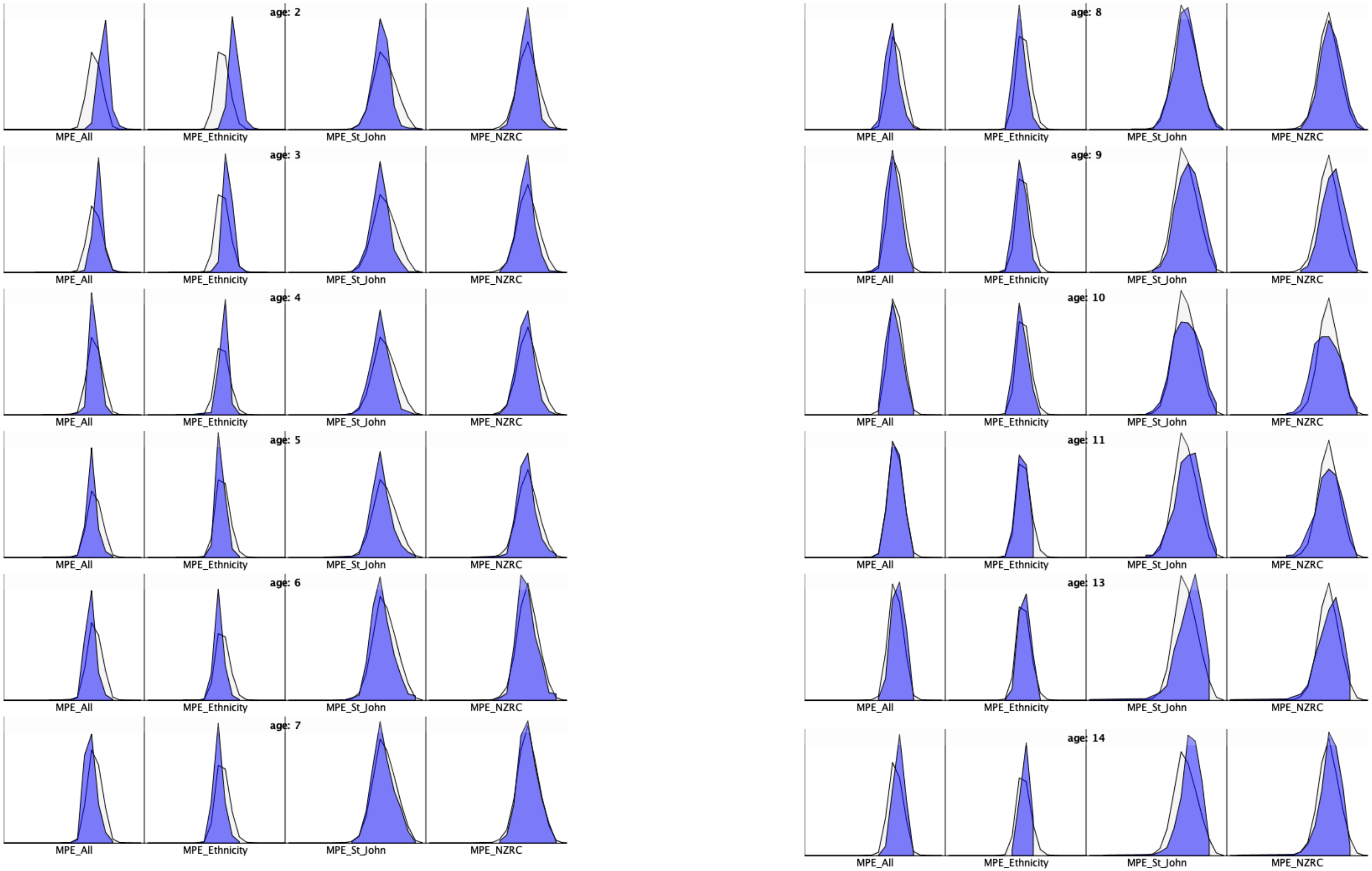


Figure 73 - Distribution of MPE grouped by age

Table 32 presents the proportion of weight estimates within a given percentage (1 0%, 20% and 30%) of the actual weight of children. The regression equations that include ethnicity are more accurate than other methods with a higher proportion of weight estimates within 10% and 20% of the actual weight.

Table 32 - Comparison of weight estimation within 10%, 20% and 30% for children aged 2 to 14 years

Estimation Method (Statistics NZ dataset[63])	**Percent of estimates within a given percentage of actual weight**			
	n	±10%	±20%	±30%
All	8413	36.5	70.9	**100**
Ethnicity	8413	**41.1**	**76.1**	**100**
NZRC	8413	35.4	71.8	**100**
St John	8413	33.6	70.4	**100**

The heatmap within Table 33 shows where each estimation method is most accurate (green) and least accurate (red). This data shows a similar trend to Table 31, where the regression model/equation is more accurate for children under four years when ethnicity is not considered. Therefore post-doctoral work should include investigation of model selection or transformation of data to alleviate this.

Table 33 - Percent of estimates within a given percentage grouped by age

	Estimation Model											
	All % within			**Ethnicity % within**			**NZRC % within**			**St John % within**		
	10	**20**	**30**	**10**	**20**	**30**	**10**	**20**	**30**	**10**	**20**	**30**
2 years	32.5	38.2	29.3	9.3	30.6	60.2	29.7	40.8	29.5	29.7	40.8	29.5
3 years	60.9	30.6	8.5	35.1	39.1	25.9	35.7	42.1	22.2	35.7	42.1	22.2
4 years	31.6	42.8	25.6	69.2	25.7	5.1	36.3	40.4	23.3	36.3	40.4	23.3
5 years	20.3	28.3	51.3	47.7	36.5	15.8	41.4	37.8	20.9	41.4	37.8	20.9
6 years	20.2	30.1	49.7	32.6	39.3	28.2	41.8	35.7	22.6	41.8	35.7	22.6
7 years	24.8	32.6	42.5	26.6	36.8	36.6	36.4	40.1	23.5	36.4	40.1	23.5
8 years	28.1	32.8	39.1	37.0	36.6	26.4	30.9	37.2	31.8	30.9	37.2	31.8
9 years	35.5	33.7	30.8	37.7	35.9	26.4	31.2	35.1	33.7	31.2	35.1	33.7
10 years	33.0	36.2	30.9	34.9	35.9	29.2	43.7	30.3	26.0	39.3	30.5	30.2
11 years	37.8	32.2	29.9	42.8	36.0	21.1	37.3	32.3	30.4	29.9	35.1	35.1
12 years	41.0	34.6	24.4	43.8	33.7	22.5	33.7	30.7	35.6	26.2	33.5	40.2
13 years	39.2	35.8	25.0	39.1	37.5	23.4	34.7	29.4	35.9	29.3	30.3	40.5
14 years	46.4	35.5	18.1	51.0	30.8	18.2	27.0	33.6	39.4	18.1	28.8	53.2

Green shading represents better accuracy and red represents poorer accuracy

Table 34 shows the effect of ethnicity on the percentage of weight estimates within a given percentage of their actual weight. The most apparent finding is concerning St John and NZRC estimation methods which do not provide the accuracy that other estimation methods do for Pacific children.

Table 34 - The percentage of weight estimates within a given percentage (10%, 20% or 30%) of their actual weight grouped by ethnicity.

All	Ethnicity

	within 10% %	within 20% %	within 30% %		within 10% %	within 20% %	within 30% %
Maori	37.8	34.3	27.9	Maori	39.5	35.4	25.2
Pacific	37.5	36.7	25.8	Pacific	39.7	35.0	25.4
Asian	36.1	35.2	28.6	Asian	40.3	32.7	27.0
Other	35.0	33.8	31.2	Other	42.9	35.2	21.9

	NZRC				St John		
	within 10% %	within 20% %	within 30% %		within 10% %	within 20% %	within 30% %
Maori	29.6	37.4	33.0	Maori	28.1	36.9	35.1
Pacific	22.9	33.3	43.9	Pacific	19.6	35.0	45.3
Asian	43.0	35.1	21.9	Asian	41.6	38.6	19.8
Other	39.6	36.3	24.1	Other	37.4	36.6	26.0

Green shading represents higher percentages of weight estimates while red represents lower proportions of weight estimates

The analysis using limits of agreement was undertaken by calculating the difference between each actual weight and weight estimate. A simple t-test was run revealing results in Table 35 with the addition of calculated limits of the agreement at 95% CI.

Table 35 - Limits of Agreement (LoA) for Statistics NZ Dataset[63] weight estimates

		Difference		**Limits of Agreement**	
Difference for method	**n**	**Mean**	**SD**	**Upper**	**Lower**
All	8413	6.8	5.3	17.2	-3.7
Ethnicity	8413	**5.7**	**5.2**	**16.0**	**-4.5**
St John	8413	8.8	9.6	27.7	-10.0
NZRC	8413	9.9	10.6	30.7	-10.9

Bland Altman plots are commonly used in literature when comparing two measures. They show the relationship of the difference between the two measures in relation to the mean of all measures.[290, 291] Figure 74 to Figure 77 illustrate that the most accurate weight estimation method overall is the regression model/equation that includes ethnicity as the mean is closer to zero and the limits of agreement are the narrowest. What is evident from these graphs is the tendency of the NZRC and St John formulae to underestimate the weight of children as they become heavier or older

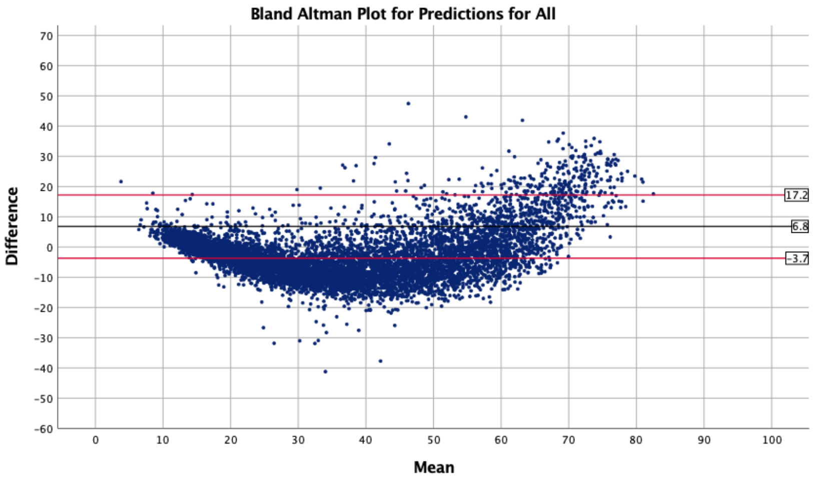


Figure 74 - Bland Altman plot of regression equation/model (All) weight estimate verses actual weight

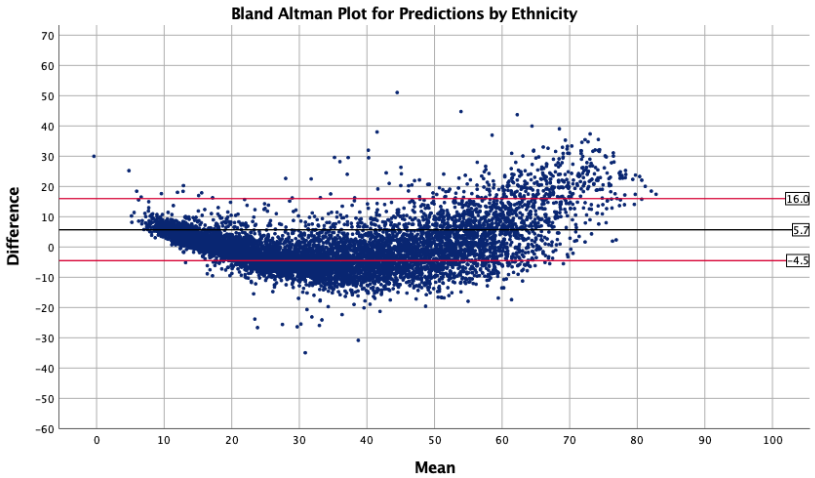


Figure 75 - Bland Altman plot of regression equation/model (ethnicity) weight estimate versus actual weight

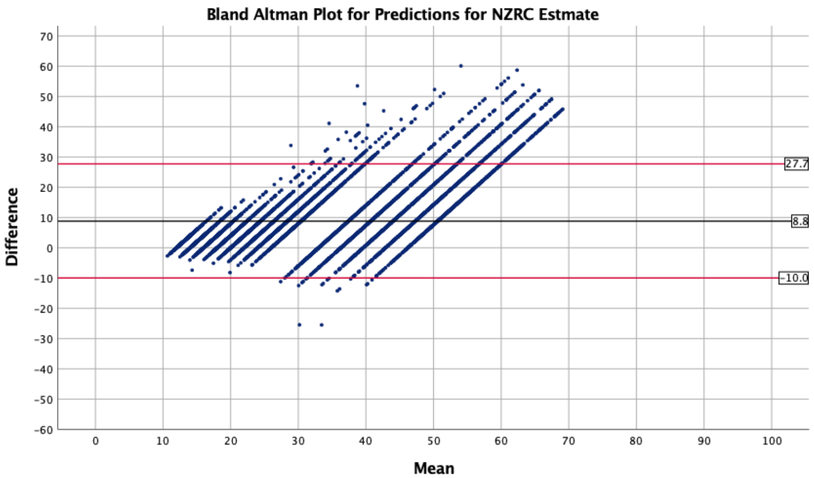


Figure 76 - Bland Altman plot of NZRC estimate versus actual weight

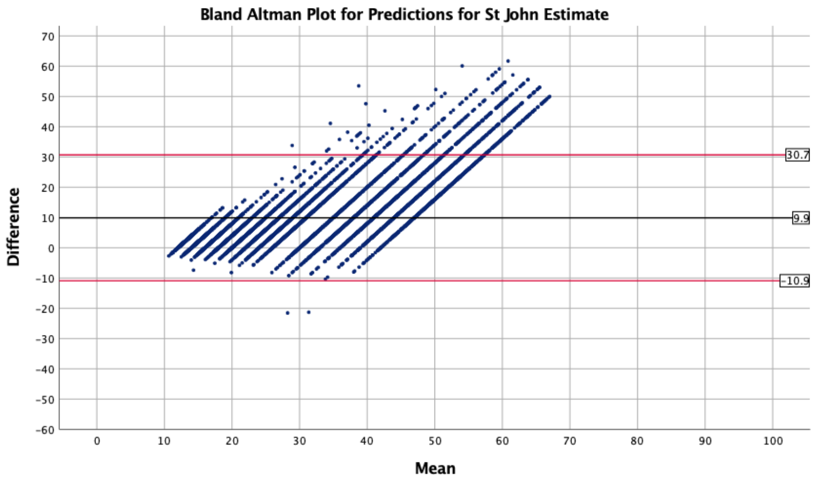


Figure 77 - Bland Altman plot of St John estimate versus actual weight

On examination of the limits of agreement for each weight estimation method when grouped by age (Table 36) it is evident that the SD and limits of agreement get wider as children age (become heavier) which is an expected finding. Grouping by age also shows a similar pattern to other results with children under the age of 4 years the regression model/equation is more accurate without the inclusion of ethnicity and for children 4 – 14 years including ethnicity is a variable makes weight estimation more accurate. All methods of weight estimation tested became less accurate with increasing age or weight. Therefore, future post-doctoral research will involve examination of data transformation and other models such as exponential regression, neural networks and other forms of machine learning.

Table 36 - Limits of agreement grouped by age

	All				Ethnicity				St John				NZRC			
Age	**Mean**	**SD**	**Upper Limit**	**Lower Limit**	**Mean**	**SD**	**Upper Limit**	**Lower Limit**	**Mean**	**SD**	**Upper Limit**	**Lower Limit**	**Mean**	**SD**	**Upper Limit**	**Lower Limit**
2	2.4	3.5	9.3	-4.6	5.3	3.5	12.2	-1.6	2.8	3.2	9.0	-3.4	2.8	3.2	9.0	-3.4
3	-0.3	3.2	6.0	-6.5	2.7	3.2	8.9	-3.6	3.0	3.2	9.2	-3.2	3.0	3.2	9.2	-3.2
4	-2.6	3.2	3.8	-8.9	0.4	3.2	6.6	-5.8	3.5	3.9	11.1	-4.2	3.5	3.9	11.1	-4.2
5	-4.4	4.3	4.0	-12.8	-1.5	4.2	6.8	-9.7	4.4	5.2	14.5	-5.7	4.4	5.2	14.5	-5.7
6	-6.0	5.1	4.1	-16.0	-3.0	4.8	6.5	-12.4	5.2	6.3	17.5	-7.1	5.2	6.3	17.5	-7.1
7	-6.4	5.3	4.1	-16.8	-3.4	5.1	6.6	-13.4	6.5	6.5	19.3	-6.3	6.5	6.5	19.3	-6.3
8	-6.1	7.4	8.3	-20.5	-3.0	7.1	10.9	-17.0	8.8	8.8	26.0	-8.5	8.8	8.8	26.0	-8.5
9	-5.7	7.6	9.2	-20.6	-2.7	7.2	11.5	-16.9	11.3	9.7	30.3	-7.7	11.3	9.7	30.3	-7.7
10	-4.8	9.9	14.6	-24.2	-1.8	9.4	16.6	-20.2	11.9	12.3	36.0	-12.2	8.9	12.3	33.0	-15.2
11	-3.3	10.2	16.6	-23.2	-0.3	9.5	18.4	-18.9	14.4	12.5	38.8	-10.1	11.1	12.5	35.5	-13.4
12	-1.3	10.7	19.7	-22.4	1.7	10.2	21.6	-18.3	17.5	13.1	43.1	-8.2	13.9	13.1	39.5	-11.8
13	-0.6	11.2	21.3	-22.5	2.6	10.5	23.2	-17.9	18.4	13.2	44.4	-7.5	14.5	13.2	40.5	-11.4
14	0.4	10.5	20.9	-20.2	3.8	10.0	23.4	-15.8	19.2	11.9	42.5	-4.1	15.0	11.9	38.3	-8.3

7.3.4 Experiment Two

Accuracy of regression equation/model is calculated using a dataset collected for this study (WEWW Dataset) in comparison with weight estimates calculated using the NZRC and St John methods. This experiment is repeated with the height measured using the WEWW application camera (noted as $_c$) and stadiometer (noted as $_s$).

Experiment two is achieved through two research questions.

- **RQ3:** How accurate are weight estimates using camera height with regression model/equation compared with existing estimation methods?
- **RQ4:** How accurate are weight estimates using actual height with regression model/equation compared with estimation methods?

7.3.5 Research Questions Three and Four

This experiment required measuring and weighing children, for both RQ3 and RQ4, therefore recruitment of children will be discussed. Recruitment and data collection processes are discussed here in relation to both experiments.

Recruitment of child participants

Child participants were recruited via their parents. The researcher contacted the parents of children via professional networks, such as email to the researcher's ambulance and university colleagues, as well as personal and social networks asking these people to disseminate an invitation to participate to their contacts. Parents were to contact the researcher if their child could participate. The advertisement for child participants can be seen in section 10.4.8 in **Error! Reference source not found.**.

Data collection

Data was collected between July and November 2018, with children aged 1 – 14 years who were able to follow instructions eligible to participate. Children were excluded if the researcher directly taught the children in her capacity as a Youth Leader for St John or parents were taught in her role as a Lecturer at a University. Furthermore, children were excluded if they could not follow simple instructions or remove heavy outer clothing. No children met the exclusion criteria.

Each child was measured and weighed by the researcher three times using International standards for anthropometric assessment.[292] After this, children were measured using the WEWW application three times with the median value of all measures included in the dataset for this study. The median was chosen over the mean as this is an established protocol in previous NZ weight estimation literature[14, 16, 17] and anthropometry guidelines.[292]

The equipment used to measure children was a Wedderburn portable height rod[293] (stadiometer), which is made from toughened plastic with a head plate which allows the user to read the height comfortably. Manufacturers report that the height rod was designed in conjunction with paediatricians and the Child Growth Foundation[293] and the use of the Wedderburn Portable Height Rod have been established as a gold standard measure in multiple New Zealand studies involving children.[14, 16, 294]

A Seca 813 High Capacity Electronic Flat Scale (Hamburg, Germany) (professionally calibrated one week before data collection began) was used to weigh the children.[295] The capacity of this scale is up to 200 kg weight and graduations are in 100-gram increments.[295] The flat scale was used in this study as per the manufacturer's instructions.[295] As with the Wedderburn Height Rod several studies have established the use of this model of scales for weighing children in research studies performed in NZ.[14, 16]

The process used to measure each child was as follows:

1. Provide age-appropriate information sheets to children and parents.
2. Ensure the equipment is cleaned and set up correctly.
3. Explain the process of height and weight measurement as well as an overview of the WEWW application to each child and their parent or guardian.
4. Gain informed consent from parents and written or verbal permission from children.
5. Ensure any heavy clothing and shoes the child is wearing are removed.
6. Measure the height of the child
    a. Explain how the height rod is used to measure the child and family.
    b. Ask if the child and family have any questions about this process and answer these appropriately.
    c. Ensure the child is aware that the head plate of the height rod will touch their head.
    d. Position the child on the stadiometer as per ISAK anthropometric standards for measurement of stature (including, stance, head position and foot position).
    e. Slide the head plate down to touch the top of their head and record the measured height in cm.
    f. Ask the child to step off the stadiometer.
    g. Repeat items c to e twice more.
7. Measure the weight of the child
    a. Explain to the child and their family how the scales work and that their weight reading will not be mentioned verbally (to ensure privacy and stigma associated with weight measurement).
    b. Ask if the child and family have any questions about this process and answer these appropriately.

   c. Ensure the scales placed on a flat surface and are turned on and showing zero.
   d. Ask the child to step on to the scales and ensure they are positioned correctly (e.g. not holding the wall).
   e. Allow the weight measure to settle by waiting until it does not change.
   f. Record the weight measure.
   g. Ask the child to step off the scales.
   h. Repeat items b to f twice more.
8. Measure the child using the WEWW application
   a. Explain to the child and their family how the WEWW application works and the requirements of the child.
   b. Ask if the child or family have any questions about this process and answer these appropriately.
   c. Open the WEWW application and enter the child's demographic data (age, gender, ethnicity).
   d. Position the child lying flat and supine on a yoga mat and stay still.
   e. Point the iPhone camera at the floor so that the WEWW application can pick up the plane.
   f. Once the yellow square has a solid border, line up the cross with the child's head and tap the screen.
   g. Line up the cross with the child's heel and tap the screen.
   h. Let the child move around while results are recorded.
   i. Repeat steps b to g twice more.
9. Thank the child and their family for participating in this study.

Data Analysis

Firstly, the dataset collected in this study was explored, including the demographic data reported. Skewness and kurtosis were calculated to describe the distribution and normality of data. After this, the internal reliability of measurements across children was tested using the Cronbach's alpha.

The data from each child was entered into the test application and provided a prediction of weight from their height measured with the stadiometer and another from their height measured using the WEWW application camera. This was then added to the dataset collected in this study. This means that the dataset collected in this study now contained the following information about each child: Age, Gender, Ethnicity, Height, Weight, research model/equation weight estimate using stadiometer measure, research model/equation weight and height estimate using camera measure weight estimate, NZRC weight estimate, St John weight estimate

Data analysis techniques identical as those outlined in the data analysis portion of section • that were used to determine MPE, proportion of children with a weight within a given percent of their actual weight and limits of agreement. The only difference is that the dataset analysed in this experiment was collected for this study (WEWW dataset).

Results

Demographics for the children measured are shown in Table 37. Internal reliability of measurement data that was collected was checked using a Cronbach's alpha reliability test. This revealed a Cronbach’s alpha score of 0.897 and 0.960 using standardized measures which shows acceptable internal reliability[296] for both the weight and height measurements. The actual weight of the children measured was positively skewed (1.214) while for each of the following variables skew was considered normally distributed; estimated weight (-0.006), actual height (-0.034), and estimated height (0.035). Kurtosis for the actual weight of children was also high (1.604), with other variables such as estimated weight (-0.723), actual height (-0.726), and estimated height (-0.730) lower. However, no skewness or kurtosis values are outside one SD and therefore these are all of these results show a normal distribution.[278]

Table 37 - Demographics of children measured

	n	%
Age		
2	2	8.7
4	1	4.3
5	2	8.7
6	3	13
7	1	4.3
8	2	8.7
9	1	4.3
10	2	8.7
11	2	8.7
12	2	8.7
13	2	8.7
14	3	13
Gender		
Female	10	43.5
Male	13	56.5
Ethnicity		
Other	22	95.7
Pacific	1	4.3

7.3.6 Research Question Three and Four

Results

Firstly it is worth noting that the small dataset collected of 23 children of predominantly one ethnicity with only one or two children in each age group makes esterification and location of errors in weight estimation challenging. For these reasons, the data set will be looked at as a whole with future replication of these experiments by collecting a larger dataset planned for post-doctoral research. Some elements of this dataset can be examined, such as the variance and agreement of measures between the stadiometer and camera height measurements to determine whether there is a significant difference between these measures.

As all measurements of height and weight for children were performed by the researcher three times, the variance between these can be examined. The Kendall tau b correlation between the three measurements with a stadiometer show almost perfect relationship between measures (Table 38).

Table 38 - Kendall tau b correlation for heights measured with a stadiometer

		Measured Height 1	Measured Height 2	Measured Height 2
Measured Height 1	τ_b	1	.984**	.992**
	Sig.	.	0.000	0.000
	n	23	23	23
Measured Height 2	τ_b	.984**	1	.992**
	Sig.	0.000	.	0.000
	n	23	23	23
Measured Height 2	τ_b	.992**	.992**	1
	Sig.	0.000	0.000	.
	n	23	23	23

** Correlation is significant at the 0.01 level (2-tailed).

For the camera measurements the three measurements show a very strong correlation between measures (Table 39).

Table 39 - Kendall tau b correlation for heights measured with a camera

		Estimated Height 1	Estimated Height 2	Estimated Height 2
Estimated Height 1	τ_b	1	.889**	.929**
	Sig.	.	0.000	0.000
	n	23	23	23
Estimated Height 2	τ_b	.889**	1	.913**
	Sig.	0.000	.	0.000
	n	23	23	23
Estimated Height 2	τ_b	.929**	.913**	1
	Sig.	0.000	0.000	.
	n	23	23	23

** Correlation is significant at the 0.01 level (2-tailed).

The mean actual difference (MAD) between the median stadiometer and median camera measures is minimal at -0.12 cm (SD 2.5 cm) with the mean percent difference (MPD) of 0.02 (SD 2.0%). The 2% difference between the camera and stadiometer measurements can be applied to the WEWW dataset. For the smallest child (weight 15.2 kg, height 92.45 cm) a 2% difference in height is in their height equates ±1.85 cm meaning that the weight estimation using the regression model/equation could vary by ±0.15 kg. For the heaviest (weight 75.2 kg, height 183.35 cm) a 2% difference in height equates to ±3.67 cm, meaning that the weight estimation using the regression model/equation could vary by ±0.75 kg. A more in-depth investigation of the relationship of error between camera, stadiometer and height, weight, ethnicity and gender are required in future research was larger and more diverse dataset could provide valuable insight.

What is evident in the results above is that the difference between the camera and stadiometer measurement is an area that can potentially introduce error. Kendall’s tau b correlation was run on the height measured with stadiometer and camera. Results showed a very strong correlation between the camera and stadiometer measurements ($\tau b = 0.968$, $p = <0.001$), it is challenging to interpret this result and determine the clinical effect of this as literature does not include this information about the acceptable error in weight estimation that has been validated. A potential rationale for the lack of validation is that resuscitation drugs are used off label for children, which means they have not been tested for children or safe dose for children are unknown (see Table 6 on page 14 of this thesis). This implies that the pharmacokinetics and pharmacodynamics of resuscitation drugs are often unknown for children. Therefore, planned post-doctoral work includes the validation of the acceptable error in medication doses for children. After this is complete, the acceptable error in weight estimation related to the WEWW application can be revisited.

Table 40 shows from the MPE for the regression model/equation that used ethnicity based on the stadiometer measurement was the most accurate of the weight estimation techniques, however, it was closely followed by the measurement using the camera. It is worth noting that the camera and stadiometer are both <1% different in MPE for both regression with and without ethnicity as a variable

Table 40 - MPE of all weight estimates, with the measurement from the camera in the WEWW application for comparison

Estimation Method	**n**	**Minimum**	**Maximum**	**MPE**	**SD**
All (stadiometer)	23	-56.4	17.2	-25.8	20.6
All (camera)	23	-60.0	7.3	-26.3	19.2
Ethnicity (stadiometer)	23	-41.4	37.5	**-11.3**	**15.2**
Ethnicity (camera)	23	-43.9	29.5	11.6	19.1
NZRC	23	24.0	43.2	11.6	17.6
St John	23	**-12.7**	**44.1**	15.8	**15.2**

Table 41 shows the proportion of weight estimates within a given percentage of actual weight. The most accurate method was the use of the regression model/equation that included ethnicity and used the stadiometer measurement. While this was within 10% of actual weight, the St John formula within 20% and both the NZRC and St John formulae within 30%. Clinically, a rule of thumb in literature is that a weight ±10% of the actual weight is considered accurate,[14, 16, 27] however, there is no evidence of this ever being validated making it challenging to determine the measurement error (human or camera) affects the weight estimate.

Table 41 - Comparison of weight estimation methods showing within 10%, 20% and 30% for children aged 2 to 14 years

	This Study			
	n	**±10%**	**±20%**	**±30%**
All (stadiometer)	23	21.7	34.8	52.2
All (camera)	23	26.1	56.5	**82.6**
Ethnicity (stadiometer)	23	**30.4**	60.9	69.6
Ethnicity (camera)	23	26.1	56.5	**82.6**
NZRC	23	21.7	**65.2**	**82.6**
St John	23	30.4	56.5	**82.6**

Limits of Agreement for weight estimates regression models/equations using camera and stadiometer height, St John and NZRC weight estimates are presented Table 42 with the addition of calculated limits of the agreement at 95% CI. Results show that the least mean difference is shown using the St John formulae yet, interestingly the narrowest limits of agreement were using the stadiometer with no inclusion of ethnicity. Bland Altman plots will be presented at the end of this chapter to allow easy comparison between RQ3 and RQ4.

Table 42 - Simple t-test results with limits of agreement for the Bland Altman Pots

		Difference			Limits of Agreement	
Difference for method	**n**	**Mean**	**SD**	**SE**	**Upper**	**Lower**
All (stadiometer)	23	37.9	3.1	15.0	**23.0**	**31.8**
All (camera)	23	37.9	3.1	14.8	43.9	31.8
Ethnicity (stadiometer)	23	35.6	3.0	14.4	41.5	29.7
Ethnicity (camera)	23	35.6	3.0	14.3	41.4	29.8
NZRC	23	31.5	2.6	12.6	36.7	26.4
St John	23	**30.7**	**2.5**	**11.8**	35.5	25.8

Alpha Testing

7.3.7 Experiment Three

Alpha testing is usually considered operational testing or testing the software as it will be used when deployed.[297] For testing the WEWW application alpha testing was adapted and broken down into three components, exploratory testing, functional testing and whether the WEWW application meets the acceptance criteria.

Experiment three includes three research questions.

- RQ5: Identify and correct exploratory testing issues
- RQ6: Identify and correct functional testing issues
- RQ7: Does the WEWW application meet the Acceptance Criteria?

7.3.8 Research Question Five

Methods

Exploratory testing is a formal type of software testing, however, unlike other types of testing there are no formal plan or test cases.[298] It consists of finding issues as they arise and occurred throughout the development of the WEWW application.

Data collection

Data collection through exploratory testing took place throughout the development of the WEWW application from December 2016 – December 2018 and was closely aligned with the design cycle of the blended DSR method shown in **Error! Reference source not found.** in section 4.2.6.

Data analysis

Issues were identified, noted and fixed as they occurred.

Results

On exploratory testing during development of the graphical user interface (GUI), four problems emerged.

1. Screen one had aesthetic issues where the buttons and fields went right to the edges of the screen, meaning that the print of some labels was right against the edge of the screen. Having space at the edge would mean that this text is more comfortable to read.
2. Navigating through the GUI screens was difficult for people with large fingers on a small iPhone 7 screen, so altering the layout of the screen would make operation easier.
3. User instructions and feedback in screen two were designed to overlay in yellow or green print, which may be challenging to read in specific environments. However, blocking part of the screen for user messages cut down the viewable area. Therefore, the overlay instructions were deliberately retained until after user testing (discussed later in this chapter) to gauge the impact on users of the overlay design.
4. A spelling error in screen three was evident and required fixing (Demobgraphics should read Demographics).

As a result, the spelling error, as well as the button and field layout, were corrected (Figure 78). However, as mentioned above the visual feedback and instructions were left to determine the user preference during user testing.

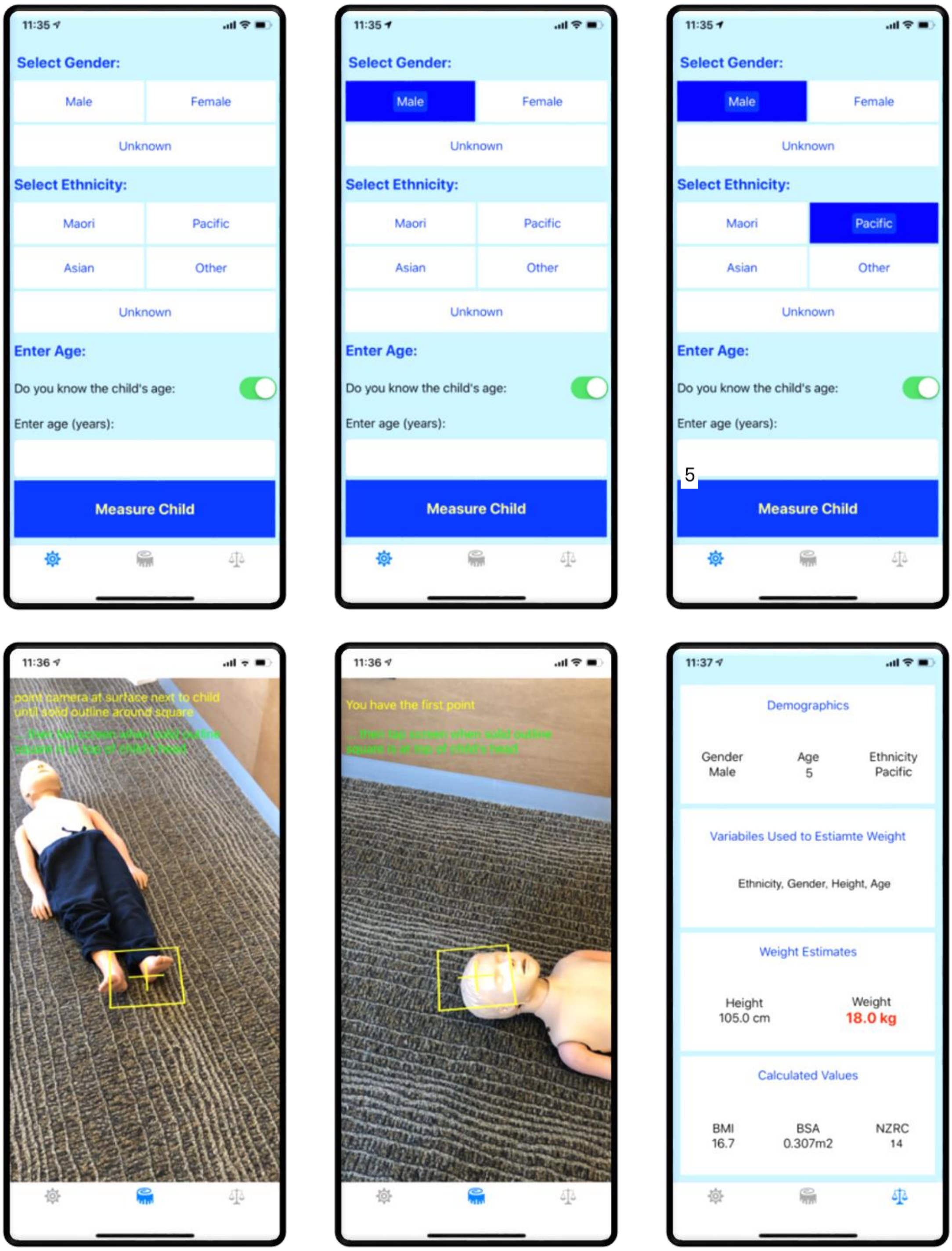


Figure 78 – Redesign of the GUI after systematic exploratory GUI testing.

7.3.9 Research Question Six

Methods

Functional testing is a form of quality assurance where the application is tested against the functional requirements. Functional testing aims to examine the usage of the WEWW application to ensure that it functions as expected and to correct any problems encountered. A definition of the term ‘function’ is required. The term function applies both to something that occurs and a block of code which relates to that specific process. According to Hamlet included linking what the program does with the code which controls it is imperative and therefore, a key component of testing the WEWW application functions.[299]Therefore, in this context function refers to a portion functionality which in turn could contain multiple functions and classes to control the application within the programming code.

The first part of the functional testing process was to review the WEWW application to determine if all functions are necessary, are included in the acceptance criteria and if they enhance the application. The second phase of functional testing included individually testing each function that the application needs to perform. To achieve this the process outlined in Figure 79 was applied to each function of the WEWW application.

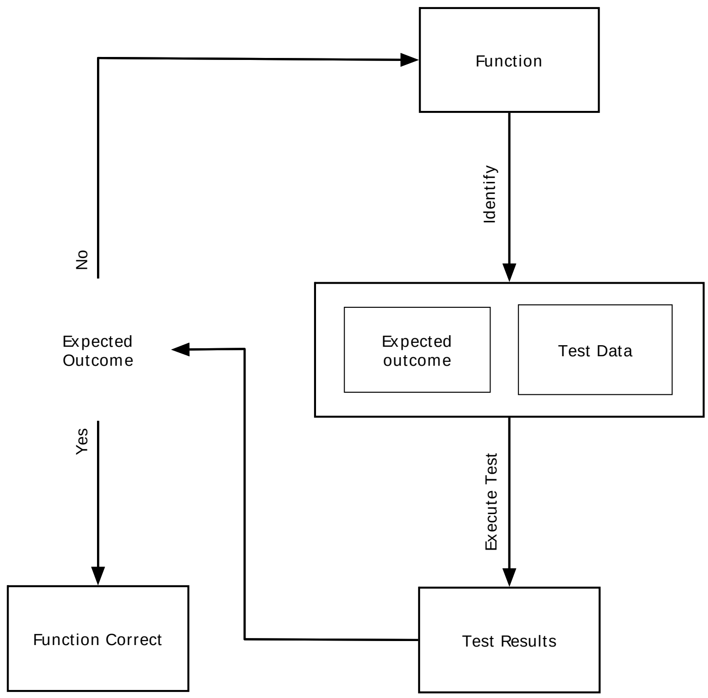


Figure 79 - Algorithm for testing each function

Data collection

Data was collated into a table for easy analysis and reporting. Table 43 shows an overview of the initial functional testing with issues and changes made to the WEWW application. The purpose of this table is to show the process followed for all functional testing throughout development regardless of the time and design cycle where testing occurred.

Data analysis

Issues were identified, noted and fixed as they occurred.

Results

An overview of data collected for research question six is shown in Table 43 with a description of these results and measures to address these discussed after the table.

Table 43 - Overview of functional testing

Function	Input	Expected Outcome	Issues Identified	Issue Fixed	Successful Retest
Select and store gender	Male, Female, Unknown or blank.	Each variable read and stored from user input.	None		
Select Ethnicity	Maori, Pacific, Asian, Other, Unknown or blank.	Each variable read and stored from user input.	None		
Enter age (years):	Age	Each variable read and stored from user input.	Age seems to appear as a password field and is not stored.	✓	✓
Measure Button Pressed	Screen tap	Move to measurement screen	None		
Focus Square appears and detects a plane.	None	Focus square changes to a closed square and moves only along the plane	None		
Focus Square moves in AR at the appropriate position and user can measure	Two screen taps	Determine two real-world points and measure the distance between these points.	None		
Appropriate user messages during measurement	None	Give user feedback on movement around the screen throughout the AR portion.	None – the colour of the messages may need to change but this will be left until user testing to determine the needs of the user.		
On second measure tap results screen shown	Screen tap	Move to the second screen at the appropriate time.	None		
Results screen shows appropriate results	None	Display results	None		
Tab menu at the bottom of the page cycles through the different screens updating information appropriately.	None	Changes to data transferred between screens and the tab menu switches between screens.	None		

Functional testing revealed that the age field was designed as a password field. What this meant was the age that the user entered was not visible to the user for checking and the data entered was not processed correctly. This posed a risk of less accurate weight estimates due to incorrect or missing data. Therefore, the age field was changed to a text field and retested.

At this point the evolving layout using a automatic resizing in the stack layout for the GUI was removed. The rationale for this was that it is not a necessary function and the resizing of components on the screen could distract the user. Figure 80 shows the changes to the settings screen.

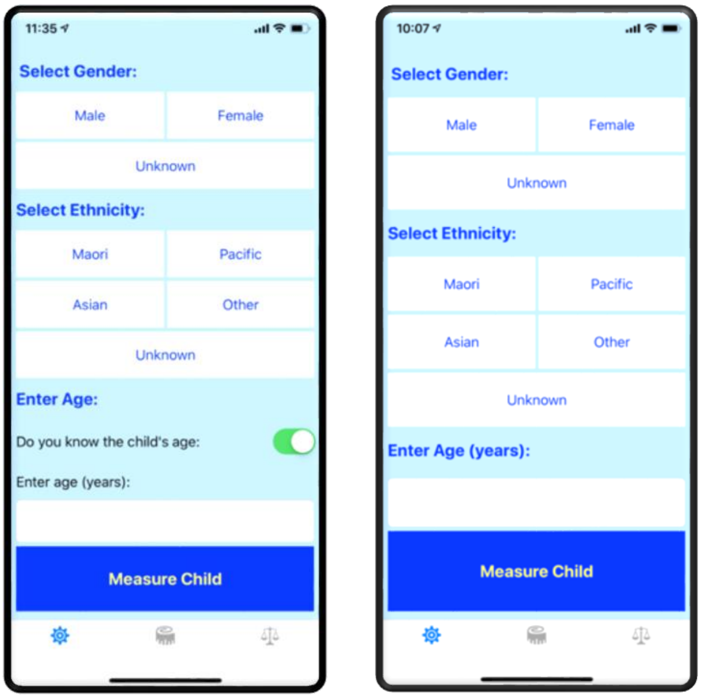


Figure 80 – Evolving screen layout (left) static screen layout (right)

7.3.10 Research Question Seven

Methods

The WEWW application will be evaluated against most recent acceptance criteria.

Data collection

In May 2019 acceptance criteria were compared with the current status of the WEWW application. Results are presented in a table in the results section.

Data analysis

Acceptance criteria were compared with the current function of the WEWW application and are either achieved or not achieved.

Results

Table 44 gives an overview of the acceptance criteria with an indication of whether these have been achieved. One criteria, labelled positioning (Artefact and child on same planar surface) is no longer applicable as the WEWW application was ultimately developed in a way that does not need an artefact. Augmented Reality (AR) and built-in iOS functions are used instead.

Table 44 - Summary of the acceptance criteria and indication of achievement

Acceptance Criteria		**Achieved**
Mobile		
1	WEWW application developed for iOS (iPhone)	✓
Accuracy		
2	Estimate weight for > 75% of sample to within 10% of their actual weight	✗
3	Demographic characteristics utilised increase accuracy	✓
4	Based on the NZ dataset to increase accuracy	✓
Environment		
5	Usable in a varied environment (e.g. non-static environment)	✓
	Offline use	✓
User Input		
6	User input for object detection	✓
7	Minimal and simple (to decrease cognitive load)	✓
Measurement		
8	Augmented Reality (AR) to detect planar surface with measurements calculated in relation to the detected plane.	✓
Positioning		
9	Artefact and child on same planar surface	N/A

N/A is not applicable

The accuracy of the WEWW application is partially achieved. While the regression equation/model consistently outperformed existing weight estimation techniques endorsed in NZ it did not reach the target of 75% of the sample within 10% of their actual weight. This could have been influenced by the small sample size, however even in the sample from which the regression equation/model were derived the accuracy was similar. This shows that future investigation of the validation techniques and accuracy on a larger sample would be beneficial.

7.4 User Testing

Both usability and acceptability testing occurred via the same set of participants. Therefore, some of the methods section will be discussed first so as not to repeat the same information.

7.4.1 Experiment Four

Usability testing consisted of an integration of observation of users while using the WEWW application along with information expressed by users during testing via the "think-aloud"[247, 299, 300] technique.

- RQ8: What do the participants thought processes while using the WEWW application?
- RQ9: How did the participants interact with the WEWW application?

7.4.2 Common methods

Consideration of sample size

Sample size calculation for usability testing this study was due to the nature of the user testing process. Testing of software is influenced by the budget and timeframe allocated for testing as well as the intended use of the application.[301] In the case of the WEWW application, no budget was available for user testing and the timeframe was approximately 5-6 weeks.

On examination of literature suggesting a sample size for mobile applications used in paediatric resuscitation, only one mobile application for streamlining checklists in paediatric resuscitation (*paedi-crisis*)[302] reported development processes. However, that study did not complete a sample size calculation before user testing. Their sample consisted of a convenience sample from 9 institutions in 2 countries with a convenience sample of 46 anaesthesiology consultants, 35 Senior Doctors, seven registrars or fellows and four midlevel providers[302] although a definition of midlevel provider was not given. What this meant was that there were no similar research studies to base a sample size calculation on.

Cazañas, de San Miguel and Parra[301] explain that a rule of thumb often used in software development is five testers that find 80% of usability issues. However, they go on to say that this common rule underestimates the required sample size for usability testing. With this in mind, the WEWW study has gone well beyond this recommendation recruiting 15 user testers which aligns with the Food and Drug Association (FDA) in the USA has suggested 15 user testers in the main group would find between 90% and 97% of usability problems.[303] However, literature also states that there is no magic number of user testers and a more nuanced approach[303] is required to determine sample size. Interestingly, neither of the authors which critique sample size for user testing suggest a new “magic number” of testers[301, 303] making selecting the appropriate sample size of testers challenging. Alongside this, the fact that this study does not use inferential statistics in user testing makes a large sample size less critical. In qualitative research methods, it is important to consider the saturation point (or information redundancy) or the point where thematic analysis provides no new information when discussing sample size. In 2014 a study of interviews and phone conversations showed that 12 interviews revealed 92.2% of codes/themes.[304] However, a downfall of this is, in traditional thematic analysis themes or codes are often developed before data collection,[305] where one could argue that this only provides coarse detail, and the detail and richness of the data gathered could be lost in superficial coding. Relating this to sample size, while superficial coding could mean less detail, it could also mean that saturation is reached with smaller sample size. Furthermore, setting the coding before data analysis/collection adds a bias of the researcher in determining the themes that will be categorised prior. Recognising this bias and in the reflexive thematic analysis[305] allows the data to be considered as constructing knowledge rather than discovering themes. The construction of knowledge fits well within the adapted Design Science methodology (Section 4.2.6) in this thesis; however, for testing of software, I believe we need to both discover and construct. For this reason, an adapted form of thematic analysis was utilised with broad headings of Bugs, Feature Requests, Manipulation and Environment as a basis further coding emerged (Appendix F – Adapted Thematic Analysis in Section 10.5.1 during analysis rather than being set before analysis. Using this more open type of thematic analysis makes determining the sample size required for validity in user testing challenging as the saturation point is not clear. With this in mind, the richness of data was considered important and determining the number of user testers was given less importance. Therefore, as one could argue that the WEWW application is a medical device which influences survival and therefore requires a larger sample size. Thus, if a publisher requires sample size, this will be stated that 5[301] to 15 users[303] is optimal with reference to data saturation influencing the ultimate choice of size.

Recruitment

The population of healthcare professional participants that utilise weight estimation regularly is small. Inclusion criteria specified that a participant must be currently working in an area where they are likely to participate in paediatric resuscitation and have the need to estimate weight. The experience of users was not an explicit inclusion or exclusion criteria as health professions likely to use this application have extensive clinical training built into their degree, which includes paediatrics.

Initially, participants were recruited via social networks and asked to disseminate an invitation to their colleagues to participate.

Colleagues at the local District Health Board and Ambulance Service were contacted via email, social media or phone asking that the invitation to participate be sent to those who were likely to estimate the weight of a child during resuscitation as a part of their job. The reach of the invitation included emails to all Junior Doctors at a dedicated Paediatric Hospital. Nurses were contacted via email and social media with email being forwarded through St John Ambulance NZ staff and being posted on social media groups.

Due to the need for site and access agreements with these services and the small number of user testers required, access agreements were not obtained for large organisations. On-site testing was not included, and all testing occurred either in public spaces or on-site at Auckland University of Technology.

Data collection

Data was collected between July and November 2018, with pre-hospital and hospital staff invited to participate if they were likely to estimate the weight of a child in their current job.

7.4.3 Research Question Eight and Nine

Methods

Users were given an approximately 2 minute demonstration of the WEWW application which included stepping through the following processes:

1. Introduction to the WEWW application
    a. Introduction to the purpose of WEWW application and the data it was constructed from
    b. Introduction to parameters (horizontal plane measures only, child lying flat on a surface)
    c. Introduction to AR and moving the phone on all axis
    d. Introduction to tapping the screen rather than swiping
2. Selection of parameters
    a. Age
    b. Gender
    c. Ethnicity
3. Measurement of length using augmented reality
4. The process to re-measure and alter parameters

Users could ask any questions (although only one did, and it clarified the need to point the phone at the floor first) and then given 5 minutes to use the application to measure objects of a known size. User testing was completed on the same iPhone by all users and observed by the same researcher who recorded their verbal comments and noted observations of how participants interacted with the WEWW application throughout testing to ensure consistency of reporting.

The researcher recorded a brief description of the environment where the WEWW application was tested in the observation notes to provide insight into the usability of the WEWW application across testing environments. In particular, the flooring was recorded by the researcher, and a light meter was built into the application to record light levels, angles of elevation and depression. However, this data was not included as there was a technical issue, and it was only recorded for around 30% of measurements. It is worth noting that the environment for the user testing measurements did vary across users as the researcher travelled to the user for their convenience. In user testing of the WEWW application, this variation of testing environments was expected and considered a simulation of pre-hospital and hospital resuscitation environments which are not consistent. While this allowed the WEWW application to adapt to these with situations, most of these were indoors with varied lighting, flooring, textures and colours. What was missing was testing outdoors in places such as sports fields. What was similar across all testing situations was the surface that the child was measured on was a consistent colour and texture, and for this reason, future development would benefit from less consistent surroundings.

Data analysis

Analysis of data was through descriptive statistics as the sample consisted of only 14 participants. Results will be presented in a table for analysis and common themes will be identified.

Results

Demographics

Fifteen participants working in areas where they were likely to need to estimate a child's weight agreed to test this application. Unfortunately, one participant did not return their consent form, so this data was not included. This left a convenience sample of 14 health care professionals to test usability. Table 45 indicates that testers were spread across all age groups with a near-even spread across genders. It is worth noting that most participants (n = 13/14, 92.9%) identified with an 'Other' (includes NZ European) ethnicity with only one outside of this demographic. Over two-thirds of participants worked in the ambulance service (n = 11, 78.6%) with fewer participants (n = 3) from other work settings. This meant that stratification and generalisation of results of user testing were not possible. Therefore, further research needs to be undertaken with other professions to ensure that that these are fairly represented.

Table 45 - Demographic Characteristics

Age	**n**	**%**
		Age
20 - 29 years	3	14.3
30 - 39 years	4	35.7
40 - 49 years	5	28.6
50 - 59 years	2	21.4
Gender		
Female	8	57.1
Male	6	42.9
Ethnicity		
Other (includes NZ European)	13	92.9
Pacific	1	7.1
General Roles		
Ambulance Staff	11	64.3
Doctor	1	7.1
Nurse	2	14.3
Current Role		
EMT (Ambulance)	1	7.1
First Responder (Ambulance)	1	7.1
ICP (Ambulance)	5	35.7
Paramedic (Ambulance)	4	28.6
Registered Nurse	2	14.3
Registrar (Doctor)	1	7.1
Years of Practice		
20 + years	7	50
15 - 19 years	3	21.4
10 - 14 years	1	7.1
6 - 9 years	1	7.1
2 - 5 years	2	14.3

User observation

User observation is summarised in this section using adapted thematic analysis to common group themes. A more detailed breakdown of this information can be seen in Appendix E – User testing results section 10.5.1.

One (n = 1/14, 7.1%) user appeared to systematically step through testing, while other testers were more ad-hoc in their approach to testing the WEWW application.

Some users (n = 5/14, 28.6%) had not used any form of augmented reality previously and all of these over aged 40 years and above. Two of these users (n = 2/14, 14.3%) favoured standing still to measure even though moving around was demonstrated.

Two users (n = 2/14, 14.3%) wore glasses for reading and appeared to have difficulty finding a comfortable distance when they began using the WEWW application. However, with practice, finding the right distance to see the screen seemed to become more comfortable for them.

Three (n = 3/14, 21.4%) users attempted to use common phone gestures such as swiping rather than tapping on the screen even though only tapping gestures were demonstrated. One (n = 1/14, 7.1%) user was extremely hesitant using smartphone gestures such as tapping on the screen and one (n = 1/14, 7.1%) person kept attempting to tap the "crosshair" even though the on-screen instructions stated, "line up the cross and tap on the screen".

One (n = 1/14, 7.1%) user attempted measurement in a noisy and crowded environment while five (n = 5/14, 28.6%) were in a quiet environment with minimal distractions. The remainder of users tested the application in environments between quiet and noisy or empty and crowded. Only one (n = 1/14, 7.1%) user attempted a measurement where what they were measuring was behind another object, however, the user continued with no problems to measure through the object in front.

Five (n = 5/14, 28.6%) of users felt that the yellow crosshair was difficult to see against a light background or suggested that a darker background would make this easier for them to see. This corresponded with the observation of difficulty in seeing the crosshair or moving to block or allow more light. When measuring on a multicoloured background, as with lighter backgrounds, users took longer to acquire measures with users moving around more to obtain a measurement. With this in mind, future research would benefit from an analysis of the time difference on differing surfaces.

Verbal comments (Think-aloud technique)

This section will summarise the verbal comments each user made during the think-aloud process using an adapted thematic analysis where common themes in observation and verbal "think aloud"[306] comments are grouped. While a more detailed table outlining these results is also available in Appendix E – User testing results section 10.5.1, it is worth noting that most users tended to focus on using the WEWW application rather than relaying their thought processes for the think-aloud protocol. With this in mind, future protocols could be altered to use techniques which would elicit more information such as a post use interview. However, in retrospective interviews, we may lose some of the user thought processes. Therefore, in future work, I would suggest allowing the users to have free use to get to know the app and then a more formal measurement with think aloud.

Each of the following comments was made by one (n = 1/14, 7.1%) user concerning the WEWW application; "it is a good idea", "easy" and "systematic" and "straight forward" to use. While two (n = 2/14, 14.3%) users stated, the WEWW application was "useful" as they were testing the application.

During testing two faults in the WEWW application were discovered and subsequently corrected, these were the age field not displaying adequately and an initial crash when the user swiped rather than clicked to move to the next screen (a common feature in many mobile phone applications). After this, the swipe gesture was coded to move to the next screen. Along with the bugs, two feature suggestions were made during the "think aloud" observation. These were to add drug information and overlay the person being measured with a grid for detection. These features will be implemented in a future iteration (post-doctoral work).

Two users expressed difficulty manipulating the moving crosshair in the AR environment. One (n = 1/14, 7.1%) stated: "most apps have the cross stationary and you don't move the phone" while the other found lining up the crosshair to measure the child "tricky" but expressed that this would most likely become easier with practice. One (n = 1/14, 7.1%) user attempted to use gestures not available in the WEWW application and stated: "Why can't I swipe?".

The most common verbal response was concerning seeing the yellow crosshair. Two users (n = 2, 14.3%) stated that it was difficult to see on a white or light background and a further two (n = 2, 14.3%) suggested they had no difficulty seeing it on a dark background, but it may be difficult to see on a light background. Another user (n = 1, 7.1%) suggested that the patterned carpet made the crosshair difficult for the phone to focus when using AR to measure the child in the WEWW application.

Two topics were not related to the use of the WEWW application but did connect with the broader context of using the application. The first user (n = 1, 7.1%) commented that the "public may wonder why a photograph was being taken" and the second (n = 1, 7.1%) said, "I have to use ambulance procedures which means I didn't need anything else". Interestingly this user went on to quote the formula from the St John Procedures[36] incorrectly.

7.4.4 Experiment Five

Ease of use and simplicity are key elements in designing any mobile application.[247] The original design of measuring user acceptance of the WEWW application was via using the Technology Acceptance Model (TAM), a disadvantage of the original TAM is that it does not include user experience and ease-of-use is not significant for experienced users.[307] The clinical professionals would know of weight estimation form and have experience in using this as a part of their training in NZ. Furthermore, as the WEWW application is novel, there is no need to analyse users prior experience of the application. However, in hindsight, experience with AR and mobile phone use identified in Experiment Four in Section 7.4.3 could indicate that this needs to be considered in the adapted TAM and this would be appropriate to be included in future research. One area which I believe needed more emphasis in this research was the impact of perceived risk, which was not overt in the original TAM. Therefore, the adaptation shown in Figure 81 builds on the work of Erasmus, Rothman & Van Eeden in 2015[285] and includes the perceived risk of harm. A disadvantage of using TAM in this instance was the recommended stratification and correlation using external variables was unable to be performed due to the small sample size. Therefore, this testing design is presented because it was planned for this PhD, and it will be used in any future research validating the use of this application.

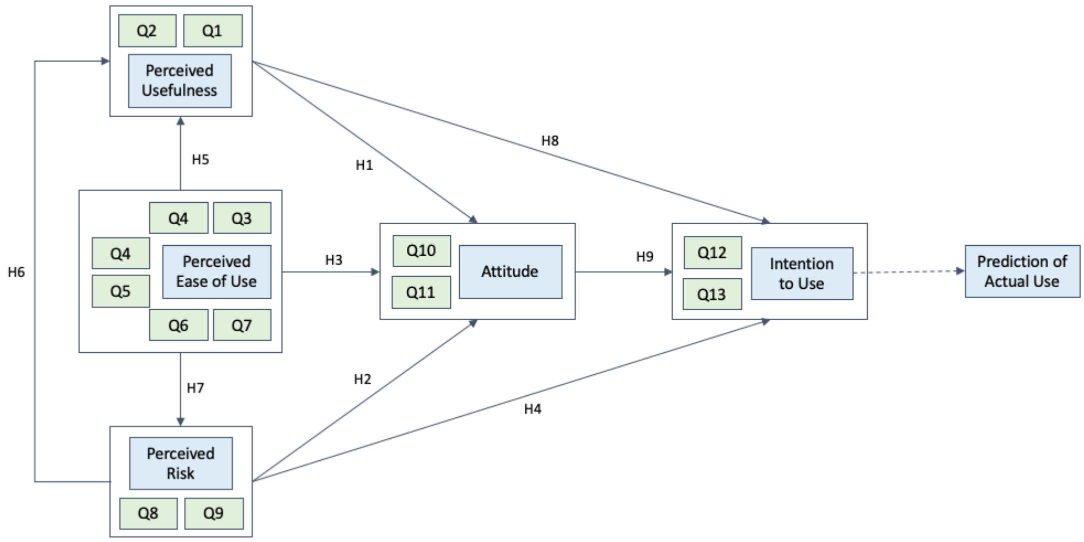


Figure 81 – Adapted from Technology Acceptance Model. [285]

Experiment Five comprises of five research questions:

- RQ10: Do users believe the WEWW application is useful in practice?
- RQ11: Do users intend to use the WEWW application in their practice?
- RQ12: Is the WEWW application easy to use?
- RQ13: What do users perceive as the risk of harm or privacy breach in using WEWW?
- RQ14: What is users' attitude towards the WEWW application?

7.4.5 Research Questions Ten to Fourteen

Methods

A post user testing survey asking for feedback based on the TAM framework that was presented above was run. Questions were adapted from the work of other authors using TAM[181, 285, 286, 308] with questions in the survey shown in Table 46. However, it is worth noting that while this survey uses the TAM methodology questions are adapted as existing question sets did not match the needs of this research in relation to perceived risk. An advantage of implementing previously validated questions is that this allows for easy comparison and measurement error is generally already known[309]. Therefore, these adapted questions will be treated as a new set of questions with no assumptions about their risk of measurement error. With this survey results will be reported using descriptive statistics rather than the proposed correlation, which means that this question set will need external validation in the future.

Table 46 - Acceptability questionnaire using the Technology Acceptance Model (TAM)

Acceptability Questionnaire	
Perceived Usefulness (PU)	
Q1	I would find WEWW useful in my job?
Q2	Using WEWW would make my weight estimation more reliable?
Perceived Ease of Use (PEOU)	
Q3	Learning to operate WEWW was easy for me?
Q4	Estimating weight using WEWW was easy for me?
Q5	The instructions given in WEWW were easy for me to understand?
Q6	Using WEWW on a mobile phone would be easy for me?
Q7	Using WEWW would make weight estimation easier for me?
Perceived Risk (PR)	
Q8	There is a risk of harming a child by using WEWW to estimate weight?
Q9	There is a risk to a child's privacy when using WEWW to estimate weight?
Attitude (A)	
Q10	I feel positive in relation to WEWW as a weight estimation tool?
Q11	It is wise to use WEWW for weight estimation?
Behavioural Intention to Use (BIU)	
Q12	Using WEWW to estimate weight is a good idea?
Q13	I would use WEWW during resuscitation if it was available to me?

Data collection

Users completed the survey questions shown in Table 46 after testing of the WEWW application. The questions were designed to look at users' perception of ease of use (PEOU), perceived usefulness (PU), perceived risk (PR), attitude (A) and behavioural intention to use (BIU). Questions were asked in a survey using a Likert scale between 1 and 5 (1 = strongly disagree and 5 = strongly agree).

Data analysis

All data analysis was completed using *SPSS* and internal consistency was reported using Cronbach's alpha coefficient. Questions related to perceived risk (Q8 and Q9) was initially worded in a way that reversed the direction of the Likert scale (1 = minimal risk and 5 maximum risk). Therefore, the results were reversed after data was collected and the analysis of the reversed effect was completed. Ordinarily, non-parametric tests would also be run for each question providing the significance. However, the small sample size (14 usability testers) could affect the accuracy of these tests; therefore, only descriptive statistics will be used to report results.

Results

Internal consistency of all questions was checked using Cronbach's alpha coefficient (0.84) and standardised items (0.90) over 14 items which shows that the survey has acceptable internal consistency[296] across questions. A breakdown of Cronbach's alpha coefficient for all sections of the survey is shown in Table 47 and illustrates that one part does not show good internal consistency. The Cronbach's alpha for the Perceived Risk of using WEWW section has Cronbach's alpha is 0.38, which is considered unreliable.[296] While this may relate to the small sample size, in the future use of this question set the reliability of question 8 and 9 requires more in-depth analysis.

Table 47 – Perceptions and behaviour associated with using WEWW

		n	Min	Max	Mean	SEM	SD	CA
Perceived Ease of Use		**14**	**3.6**	**5**	**4.43**	**0.14**	**0.53**	**0.74**
3	Learning to operate WEWW was easy for me?	14	2	5	4.36	0.25	0.93	
4	Estimating weight using WEWW was easy for me?	14	3	5	4.43	0.17	0.65	
5	The instructions given in WEWW were easy for me to understand?	14	3	5	4.50	0.17	0.65	
6	Using WEWW on a mobile phone would be easy for me?	14	4	5	4.57	0.14	0.51	
7	Using WEWW would make weight estimation easier for me?	14	3	5	4.29	0.19	0.73	
Perceived Usefulness		**14**	**2.5**	**5**	**4.14**	**0.21**	**0.79**	**0.94**
1	Using WEWW would make my weight estimation more reliable?	14	3	5	4.21	0.21	0.80	
2	I would find WEWW useful in my job?	14	2	5	4.07	0.25	0.92	
Perceived Risk		**14**	**2.5**	**5**	**4.18**	**0.25**	**0.95**	**0.38**
8	There is no risk of harming a child by using WEWW to estimate weight?	14	2	5	4.21	0.28	1.05	
9	There is no risk to a child's privacy when using WEWW to estimate weight?	14	1	5	4.43	0.23	0.85	
Behavioural Intention to Use		**14**	**3**	**5**	**4.21**	**0.18**	**0.67**	**0.94**
12	I would use WEWW during resuscitation if it was available to me?	14	2	5	3.93	0.25	0.92	
13	Using WEWW to estimate weight is a good idea?	14	3	5	4.50	0.17	0.65	
Attitude		**14**	**3**	**5**	**4.18**	**0.16**	**0.61**	**0.78**
10	I feel positive in relation to WEWW as a weight estimation tool?	14	3	5	4.29	0.16	0.61	
11	It is wise to use WEWW for weight estimation?	14	3	5	4.07	0.20	0.73	

CA = Cronbach's Alpha

Overall results of the usability questionnaire are all positive, with all but one question achieving a mean score between agree (4/5) and strongly agree (5/5). The following sections summarise the results for RQ 10 to RQ14.

7.4.6 Research Question Ten

The mean of the responses suggested that the WEWW would be useful (4.14/5), In particular, it would make their weight estimates more reliable (4.21/5) and be useful in their current job (4.07/5).

7.4.7 Research Question Eleven

Most users felt that using the WEWW application to estimate weight was a good idea (4.50/5) and would choose to use (3.93/5) this application in their job

7.4.8 Research Question Twelve

Users reported that it was easy to learn to operate the WEWW application (4.36/5) and use this (4.43/5) to estimate weight. They also felt instructions were easily understood (4.50/5) and it was easy to use on a mobile phone (4.57/5) while making it easier (4.29/5) for them to estimate weight than traditional methods of weight estimation.

7.4.9 Research Question Thirteen

Users felt that there was little risk in using the WEWW application to estimate the weight of a child for resuscitation (4.18/5) with minimal risk of harm to a child (4.21/5) or their privacy (4.14/5).

7.4.10 Research Question Fourteen

The general attitude towards the WEWW application was favourable (4.18/5) with users indicating that they felt positive (4.29/5) about the WEWW application and that it was wise (4.09/5) to use this tool.

7.5 Chapter Summary

This chapter has outlined the testing design used for the WEWW application. This has included the processes and results of alpha testing, accuracy testing and user testing.

Alpha testing included finding and fixing issues from exploratory and functional testing as well as comparing the WEWW application with the acceptance criteria. The WEWW application met all but one of the acceptance criteria, less than 75% of weight estimates were within 10% actual weight of children that is unvalidated but a common threshold in literature.[14, 16, 27] However, the regression equation/model (part of the WEWW application) have the highest proportion of weight estimates within 10% of children’s actual weight when these are compared with existing (NZRC and St John endorsed) weight estimation methods Even though this proportion is still lower than the accuracy aimed for in the acceptance criteria for the WEWW application, it does outperform methods endorsed by the governing bodies in NZ. This shows that future research needs to include verification of the acceptable error and streamlining of the regression equation/model within the WEWW application.

User testing included observation of users and the use of the “Think Aloud” technique, which highlighted some problems in the use of the WEWW application such as the colour of the background and difficulty seeing the screen. These will be addressed in future research. Overall the user response to the WEWW application was very positive, with the users believing WEWW was useful in their job, easy to use, posed minimal risk to children and most importantly that they would use WEWW in practice.

8 Chapter Eight – Discussion

8.1 Introduction

8.1.1 Revisiting the problem statement

One of the many pieces of information required early in a paediatric resuscitation is a weight estimate for the child. If this is incorrect or obtaining a weight estimate is prolonged; this could potentially harm a child, affect their quality of life or survival.[9-12] To minimise the time to treatment weight estimates are commonly used worldwide during resuscitation.[13] n New Zealand, the currently endorsed weight estimation techniques have been in use for many years and are not accurate for around half of the children.[14-17] In practice, the poor accuracy of existing weight estimation methods has led to ad-hoc changes to a weight estimate by healthcare professionals to compensate for the inaccuracy of weight estimates.

Factors including the environment[7] and diverse demographics of children[14, 16, 28, 62] can inadvertently affect the weight estimation process and therefore decrease the accuracy of each weight estimate. This concern around the consequences of inaccurate weight estimation was the primary motivation for the development of the Weight Estimation without Waiting (WEWW) application.

The aim initial of this research was to design, build and test an application that will return an accurate weight (and therefore body surface area) estimate for NZ children in multiple environments. The user interface will be straightforward with weight estimates tailored to NZ children, by using NZ-specific data and demographic characteristics of children to increase the accuracy of weight estimates.

In this chapter, I will analyse the development, design and functioning of the WEWW application against the Acceptance Criteria and associated research questions. Discussion around existing literature will also be threaded through this chapter as a knowledge of the existing solutions adds to the robustness of the design process and is an essential part of the design science model presented inFigure 8 - Blended DSR model used for this research

in Chapter Four - Methodology which underpins the design of this research.

8.2 Relevance of the WEWW application

After having worked in paediatric resuscitation in both hospital and pre-hospital settings, the researcher realised how inaccurate and inconsistent the weight estimation process was in both environments. This observation was backed up by literature that describes a resuscitation situation as decision dense, chaotic, crowded and noisy,[7, 8] which can distract from the task at hand or the decision requiring attention.[310] Along with this, the inaccuracy[16, 17] of current age-based weight estimation methods endorsed by the New Zealand Resuscitation Council (NZRC) and St John Ambulance[18, 36] means that weight estimations using these techniques are not accurate in more than half of NZ children.[14, 16] Furthermore, while some alternative weight estimation techniques for NZ children exist these have not been adopted or validated since their publication in 2016[14] which makes adoption and validation of this research paramount after development is complete. Plans for validation of this solution are to continue with research validating the accuracy of the WEWW application and refining the user interface. In the meantime, publish the accuracy, methodology and design of the application as it stands. With this information formally approach the Medical Director of St John Ambulance (Dr Tony Smith) and a Councillor of Resuscitation New Zealand (Dr Richard Aickin) suggesting a partnership for validation. During my career as Emergency Nurse and Ambulance Officer I have worked with both of these people and both are aware that this research is in progress.

Working in resuscitation is prone to error[5] as it is fast paced, decision-dense and time critical with multiple teams with similar but not identical priorities working in the same physical space.[7, 8] The actions of the resuscitation team are not only influenced by the environment but also the context surrounding it[5, 311] which often includes staff working under constant pressure, and with varying skill mix and levels of experience.[312] All these factors present a risk of increased error weight calculation in resuscitation[311] and has led to extensive consideration of the clinical nature of the deployment environment in designing and development of the WEWW application.

8.2.1 Refined acceptance criteria

The WEWW application was created based on acceptance criteria (AC) which were refined throughout development, the final AC are listed below (Table 48) and these will be discussed throughout the chapter. To improve the flow of the discussion, the italicised headings used in the AC (Table 48) that have been used consistently throughout this thesis to group the acceptance criteria will continue and provide subheadings in this chapter.

Table 48 - Final Acceptance Criteria

Acceptance Criteria		Achieved
Mobile Context		
1	WEWW application developed for iOS (iPhone)	✓
2	Offline use	✓
Accuracy		
3	Estimate weight for > 75% of sample to within 10% of their actual weight	✗
4	Demographic characteristics utilised increase accuracy	✓
5	Based on the NZ dataset to increase accuracy	✓
Deployment Environment		
6	Usable in a varied environment (e.g. non-static environment)	✓
7	Artefact and child on same planar surface	N/A
User		
8	User input for object detection	✓
9	Minimal and simple user interface and workflow (to decrease cognitive load)	✓
Measurement		

10	Augmented Reality (AR) to detect planar surface with measurements calculated in relation to the detected plane.	✓

At first glance, the AC listed above look as though they have been achieved. On reflection, these are very objective goals that can be easily measured. What is not evident in the table above is the potential for refinement or improvement of WEWW application to make this ready for public use. These issues will be discussed throughout this chapter and be flagged as areas for further development or research.

8.2.2 Mobile context

An essential consideration in the design and development of the WEWW application was portability of the application and the unique needs of mobile devices. For example, the restrictions of small screen size, connectivity, lower display resolution, limited processing power and data entry methods.[247] The first AC addresses the needs this by ensuring that the needs of mobile devices are overt and accommodated throughout the development. For example specifying the iOS operating system indicates a mobile platform, while offline use indicates the need to build an application that does not require mobile data to function.

The choice of development platform for the WEWW application was initially related to funding and availability of technology for testing. Therefore, the iOS operating system was chosen for development in this study as that was immediately available at no cost. Without this constraint the Android operating system might have been a more logical choice of platform for development. Internationally, the Android operating system would be a sensible choice as it holds more than 74.15% of the market share worldwide.[313] However, the market share is not as easy to predict in NZ as the share between iOS and Android operating systems is comparable; iOS holds 50.63% and Android holds 48.76% of the mobile market as of February 2019.[313] What this means is that even though the initial development platform is currently restricted to the iOS operating system, future development of the WEWW application needs to include cross-platform development to reach a broader market share.

The decision to either produce a native (standalone for iOS) application or implement a non-native cross-platform application was crucial in the design and development of the WEWW application. This is because native applications often allow greater functionality which can streamline and enhance the user experience as well as using less processing power.[314] In a time critical situation like resuscitation, native development was chosen in the hopes that this would positively influence time to treatment and ultimately survival of the patient. Furthermore, even though computer-vision and augmented reality (AR) can be implemented across hardware and operating systems, the architecture and libraries to achieve this are not always portable across devices. These factors made developing a native application, the logical choice. In context, the native iOS version of the WEWW application implements *ARKit*[281] that readily provides much of the computer-vision functionality, whereas other libraries were providing non-native solutions with adaptations increasing the risk of development becoming more complex and time-consuming to implement and maintain.

The second acceptance criteria relates to a key design decision; this was whether to design an offline application or implement a server-client model. An advantage of the server-client model is it could easily provide portability, reduce processing on the mobile device and could potentially reduce costs of future development.[314] While a server-client design could decrease processing on the mobile device, it could increase the time to treatment or compromise patient privacy during resuscitation as the server-client design often includes multiple processes and hardware including networks, databases, operating systems, load balancing, and memory management.[250] Furthermore, the transmission of data requires mobile phone coverage and poses two risks, increased time to treatment through data transmission along with a risk to the privacy of the child photographed. While algorithms do exist for storing and transmitting medical images and information securely[315] with supporting NZ guidelines,[254] the WEWW application was designed not to store or transmit any patient information to remove the risk of related privacy breaches. This also eliminates the risk of increased time to treatment as the transmission of data is not required and the WEWW application can still be used even though NZ mobile phone coverage is sparse in some areas.[249]

8.2.3 Deployment environment

The acceptance criteria specify that the WEWW application can be used in a varied and non-static environment. A static environment would allow use of a fixed position camera and information about the environment that could make photogrammetry and therefore the development of the WEWW application simpler.[316-318] However, the requirement to work across variable and continually changing environments meant a fixed camera was not optimal. Therefore, the WEWW application was designed to need no information from the physical environment other than initial detection of the plane the child is laying on at the time of use. Once this is located, all photogrammetry measurements are calculated in relation to that plane, meaning that there is no further need to analyse any environmental information through image processing to determine measurements. In turn, lack of image processing uses less processing power[250] and removes the time that would be taken by the mobile device in examining the image, thus potentially reducing time to treatment.

However, cues from the environment may resolve some issues that users highlighted during testing — to give an example, the difficulty seeing the cross-hair (Table 52 in Appendix E – User testing results) within the WEWW application. A potential solution for this is changing the colour of the cross-hair, messages and focus square to contrast the background based on the saturation or hue detected in the background of the image; however, there is a risk that this could also increase or decrease time to treatment. This type of solution could easily be implemented in the WEWW application as colour recognition is already established in the development of iOS applications that use AR.[319] Even though adding this functionality could improve the ability of the user to see the cross-hair, implementation of this could introduce image processing load with the need to process or compare images to determine changes in the environment.[320] Literature reporting the time taken to detect and react to colour change in an AR environment are sparse. One study detects colour and uses saliency and brightness to augment images in an attempt to make components in an image more easily seen. However the authors do not specifically investigate the processing load or timeframe, however, they do state in one experiment the colour change detection caused flicker in the AR environment[320] which could be considered as indicative of increasing time in image processing. With this in mind adding the need to process images to the WEWW application as opposed to working in the AR environment could increase the time to treatment or distract the user with flicker altering cognitive load in using the WEWW application. The implications of this (as with all new features that are implemented) are that careful consideration of positive and negative effects in adding new functionality is required. For future development of the WEWW application, this includes ensuring that consideration clinical context and impact any error may have on resuscitation of a child. With this in mind, future development of the WEWW could include a protocol for implementation of new features to ensure that the functionally, purpose and safety for use in healthcare are continually considered.

To date, the two existing mobile applications that measure length for resuscitation are limited to simulated, static environments.[67, 166] While literature extensively discusses the benefits of training for resuscitation in simulated resuscitation environments[6, 13, 321-325] weight estimation software could be missing crucial context if testing does not occur in a similar setting to the intended deployment environment. This was evident in one study that uses photogrammetry principles to measure children. Authors reported that the intent of their application was for measurement of children using photogrammetry during paediatric resuscitation.[166] However, their study was not conducted in a resuscitation-like environment within the Emergency Department (ED) and photographs used for analysis were taken with children measured standing consistently against an office wall. Whereas, during resuscitation, the optimal position for advanced resuscitation is lying supine.[248, 312] Even though user testing of the WEWW application did not occur in a simulated an ED or prehospital environment. Testing did include variability of locations which could be likened to the variability of resuscitation environments across services, private care and district health boards in NZ. To ensure the adaptability of the WEWW application, testing in multiple settings with children laying down to be measured was included in this study to simulate the variability across the resuscitation environment. While this variability in the testing environment led to the identification of some issues impacting use of the WEWW application specifically related to environmental variation, for example, patterned carpet and different coloured surfaces. This process highlighted some areas that require more focussed attention future development and research. For example the relationship of lighting levels and position of the mobile device across users and the impact of people and objects in the resuscitation environment.

While the WEWW application was tested in diverse environments, a pitfall in the design of the testing plan was that all weight estimates occurred indoors and in well-lit environments. While the original test harness developed for testing the WEWW application collected data about ambient light levels along with the pitch and yaw of the pone within the application, an unforeseen limitation of this study was that a change in the code meant this data was only collected for a small portion of the sample. Therefore, this data was not reported or utilised in this PhD. What this illustrates in hindsight is the need for ensuring that test harness can function correctly throughout testing, this could include a calibration or self-test before each measurement during testing that could be removed when development is completed. This oversight means is a more in-depth investigation with a robust testing plan that includes information around the impact of lighting levels and other environmental factors on the WEWW application is required in future research.

8.2.4 Users

The WEWW application will be used in a resuscitation environment where there are often multiple decisions to be made at one time across disciplines, making the environment incredibly busy.[79] In situations like this, the design of human computer interface is imperative as poor design could potentially add to the cognitive load in an already chaotic situation which could in turn lead to further error.[5, 7]

Towards the beginning development of the WEWW application, design of the user interface caused a dilemma in a trade-off situation between the simplicity of design and use versus the accuracy of weight prediction. This trade-off prompted a more in-depth consideration of the resuscitation workflow and led to the design of the WEWW application being based on binary decisions that provide simple choices for the user. However, this redesign of the workflow is not as simple as it first seems because users can enter as much or as little information as they have (or choose), which in turn can affect the accuracy of weight prediction. For example, when all information (height, age, gender and ethnicity) was examined in the *test dataset* from statics NZ and the smaller dataset used in this study height the MPE was-1.1 (SD = 23) and -11.3 (SD = 15.2) respectively whereas using the height variable the MPE was 1.7 (SD = 24.3) and -16.0 (SD = 20.7) respectively. What this means here is the error increases when fewer variables are used in weight predictions in the case of the larger test dataset this is by 0.4% versus 4.7% in the smaller dataset collected in this study. The information around accuracy and selection of variables was implied to users during testing, in a statement during the demonstration explaining that height was the base measure and addition of ethnicity and age could make results more accurate. It is worth noting that the literature suggests that increasing the variables used in regression modelling does not necessarily improve the accuracy of predictions.[274] Meaning that careful consideration of variable selection needs to occur before any changes or updates are made to workflow or WEWW application. While adding a popup that warns of decreased accuracy with less variables may alleviate this, it could potentially increase time to treatment. This means that training for clinicians around the need to enter appropriate information to get the best results is a fundamental. Furthermore, policies and documentation could also work towards ensuring the best practice for using the WEWW application.

Even though policies and documentation could streamline the use of the WEWW application the standardisation of these needs consideration. For example the WEWW development was complicated by differing weight estimation policies between organisations[18, 36] with one sector giving choice of weight estimation method while others do not. One participant in the testing of the WEWW application highlighted this difference in policy with the comment: "I have to use ambulance procedures which means I didn't need anything else." This disregard for any other weight estimation techniques shows the balance or trade-off that clinicians need to achieve between EBP and strict adherence to clinical procedures. While this comment may indicate the operational need to work within procedures, it does highlight the protocol driven nature of healthcare and need to balance EBP with safety and consistency. In particular this affects the ambulance services that are heavily dependent on clinical protocols.[36] In contrast to this, NZRC guidelines[18] are vague; specifying that clinicians use a particular age-based method known to be inaccurate,[14, 16, 17] and then stating that length-based methods may be better for obese children with no indication of which length-based estimation method to use or how to use it.

The choice between the inaccurate NZRC formula and unspecified "length-based" weight estimation methods produces an interesting dilemma. As a mismatch occurs between the expectation of registration bodies like Nursing[258] and Medicine[257] Councils that expect clinicians to use evidence-based practice (EBP), and the protocols and policy provided around weight estimation.[18] Policies seem to favour age-based weight estimation techniques which literature shows to be less accurate,[14, 16, 17] and therefore, could be considered asking clinicians not to use evidence-based practice. The choice of weight estimation methods by regulating bodies is perhaps more complicated than being solely reliant on EBP. The literature revealed no insight into clinicians choice to use age-based weight estimation techniques as opposed to the more accurate length-based methods of weight estimation. Future research around the choice of weight estimation technique could inform policy and ultimately the design, development and accuracy of applications like the WEWW application.

With minimal NZ literature available around designing applications for healthcare providers[88, 261] or legislation governing these applications,[260] one could argue a heavy reliance on clinicians use of EBP as well as clinicians' legal and ethical[256] practice in using health applications. For example, the WEWW application has no method for disabling the taking of screenshots when using AR to measure a child, which relies on the health practitioner to act ethically and in accordance with the law concerning storing and sharing of health information. With privacy breaches related to digital health becoming more commonly reported[314, 326, 327] this begs the question, in the digital era, is reliance on ethics or the morals and values of healthcare professionals enough? Analysis of this situation has led to the conclusion that more information around application design for healthcare in NZ is required.

Consideration of the people who interact or are influenced by a health-related application is imperative in the design and development process.[328] With technology continually evolving, developing an algorithm to estimate weight is not enough and understanding the user context is essential.[310]The Blended DSR model used to develop the WEWW application can be considered user-centred design[328] as usability testing was included and informed the development process and acceptance criteria. One could argue that the researcher defining the initial acceptance criteria for this project is not user-centred. However, the researcher could be considered an expert as she is a clinician with extensive experience in paediatric resuscitation across disciplines. In software development requires a broader approach to provide not only the solution but rigour in design, development and any associated research.[167, 329] Therefore, the acceptance criteria evolved and consultation with experts is also overt in the model underpinning the development of the WEWW application.

Interestingly, a paper presented at an NZ conference examined 20 freely available mobile health applications and all showed no privacy or security issues.[330] However, the country of development for each of these applications was not listed and regulation and guidance for application developers may vary internationally. Some guidance on the sharing[226, 251] and security[254] of health information in NZ exists, however, this often refers to information planned to be shared or stored by the application (for instance, data in an electronic health record). What is missing is guidance on unintended information sharing by the user with blocking of this ability relying on the morals and values of the developers in ensuring that sharing of this information is impossible.

During design of the WEWW application the intention had initially been to utilise the protocol driven nature of healthcare with the legal and ethical stance around information sharing expected by administering bodies to regulate and ensure the safe use of the WEWW application. However, with the disparity around what regulating bodies and EBP suggests, and the rise in digital privacy breaches are these assumptions around regulation of the WEWW application enough? The need to even ask this question implies that further research, guidance and regulation around application use in healthcare in the NZ context is required. Therefore, future research will investigate the need for regulation or restriction of the WEWW application as well as the feasibility of implementing training and independent registration of users for the WEWW application.

One of the questions often unknown in non-commissioned novel software design is ‘will it actually be used?’ For this reason the Technology Acceptance Model (TAM)[285] was incorporated as a part of the user testing phase in development of the WEWW application. While the adapted TAM indicated that users testing WEWW application believed it was useful and would assist in estimating weight, there was a disparity between intention during resuscitation (3.9/5) and whether they thought the application was a good idea (4.5/5). This is in line with some of the challenges in adoption of technology recognised by software developers,[331] for example, user resistance, the impact of outside forces, such as regulation and compliances with policy and procedure which were highlighted in the discussion above (pages 166 – 167) regarding EBP versus following protocol or procedure. Future development of the WEWW application would benefit from more in-depth user testing with specific attention paid to individual professions use of the application. This could include addressing intention to use and adoption over time with plans for implementation tailored by profession. For example, the protocol driven prehospital environment where staff act under the discretion of the medical director may benefit from a coordinated change on a specific date, whereas, hospital environments where EBP encouraged for individual clinicians may benefit from an adoption plan that is more staged or continual.

Interestingly, both existing applications that partially address weight estimation in paediatric resuscitation, *Helix[67]* and *Optimizer*[166] do not report user testing or intention to use but focus on accuracy. What this means is that this study is the first to investigate users attitude, ease of use and intention to use and perception of risk for using mobile technology in weight estimation during paediatric resuscitation. However, being the first to investigate usability of this particular application means little guidance on the nuances of user testing this particular application. In hindsight, a more structured user test, rather than free use could have given more comparison between users, however, free use may have allowed more detection of issues. With this in mind future development and research would benefit by incorporating two tiers/streams of user testing, an early free use session where issues are identified and a later one that included a more structured test of user accuracy and interaction with the application.

Results showed that users’ attitude toward the WEWW application was positive. Testers felt the WEWW application was useful, a good idea and would make their weight estimates more reliable.

A minimal perception around risk of harm to children or their privacy was reported, however, one user did comment that bystanders may wonder why they were taking photographs of a child during resuscitation. This raises a valid concern, such as the reaction of patient's families from cultures where strict beliefs around having their photograph taken, or those who do not want this method of weight estimation used. While this concern could be addressed in user training related to legal and ethical considerations during resuscitation, in anticipation further investigation of these considerations is warranted with clear protocols and guidelines around this for clinicians using the WEWW application.

Users felt it was easy to learn and use the WEWW application and suggested it was easier than traditional weight estimation techniques. However, observation of users found those who wore reading glasses initially struggled with focussing on the smartphone screen while wearing these. As smartphones become more common in society, consideration needs to be given to the health needs of users. For example, consideration of users who develop presbyopia and require reading glasses. Little evidence specifically addresses presbyopia and the issue of reading glasses in mobile application design. A conference paper addressing heuristic characteristics in usability[332] mentioned the need to consider the use reading glasses for people using smartphone applications. However, other than general principles relating to visual heuristics, these authors did not suggest any way to explicitly work with those who have difficulty focusing on the smartphone screen. While the phenomena of presbyopia was observed during user testing, it is likely that other characteristics such as experience using AR or smartphones may also have influenced this finding. However, due to the small sample size of usability testers in this study inferential statistics were unable to be utilised to determine relationships between findings observed or collected using the adapted TAM. Therefore further investigation of the influence of heuristic characteristics on the use of the WEWW application is required.

Similarly, users who had not used AR before initially struggled with navigating the three-dimensional environment on the screen as the cross-hair was not always in the centre of the screen. One suggestion from a user was that a grid on the detected plane or person detected might make this easier. Even though detection of the child was investigated in this research, it proved challenging and therefore automatic detection of the child being measured is planned for future releases of the WEWW application. The user suggestion of a grid to identify the child could be implemented and used to indicate body habitus. As literature already exists showing that the introduction of body habitus (which in this study uses ethnicity as a proxy) improves the accuracy of weight estimation in NZ children[14] this addition is planned as post-doctoral development.

An interesting concept regarding the WEWW application are its consumers. Are consumers of the WEWW application the users or those who are recipients of the care provided by clinicians?

While application design and development literature address the user-centred approach,[333] the secondary consumer (the child receiving resuscitation and their family) of the healthcare provided by clinicians using the application is less visible, yet in the clinical world, the child and family are the centre of care.[334#311] This means that in software development there is a risk of losing sight of those whom the WEWW application is intended to assist if only focussing on usability testing. This is partially addressed and acknowledged through the continuing investigation of the accuracy of the WEWW application to reduce error coupled with the consideration of the ethical and legal requirements around health information privacy. These are all considerations that place the recipient of care at the centre of development. Therefore, the accuracy of the WEWW application will be discussed, followed by legal and ethical requirements while the results of user testing are discussed throughout this discussion chapter.

8.2.5 Accuracy

Medications in paediatric resuscitation are complex and often clinicians are prescribing for children where the optimal safe dosing is considered unknown for children. As an example the optimal paediatric dosing and frequency of administration of Adrenaline (a vasoconstriction medication used in cardiac arrest) is unknown.[66]The New Zealand Resuscitation Council (NZRC) state that an initial and subsequent dose should be 10 mcg / kg with a maximum dose of 1 mg. Yet the Medsafe (NZ Government Formulary Information) suggests a different dosage. In cardiopulmonary resuscitation these guidelines both share the same initial dose. However, the Medsafe data sheet then suggests 100 mcg / kg weight which can be repeated every five minutes with no maximum dose specified.[335] The ambiguity of information which is current for both organisations shows the complexity of prescription and administration of medications in a paediatric resuscitation. The NZRC say that the higher dose of 100 mcg / kg can cause hypertension and tachydysrhythmias providing lower short term survival rates.[66]However, the Medsafe data sheet for Adrenaline was updated the most recently so could be considered the most up to date information does not acknowledge this finding. Furthermore, no references were included for the information provided in the government formulary (Medsafe) meaning the validity of use of the higher dose is unknown.

With the disparity between medication doses reported by the two agencies along with the lack of research on therapeutic levels of Adrenaline for children there is a potential for human error due to prescribing instructions which could be compounded by error in weight estimates. Table 49 shows the application of the validated dose of 10 mcg / kg of Adreanline applied to the mean weight for each age group in the test dataset from Statistics New Zealand used in this study. Only the NZRC guideline suggests a maximum safe dose of 1 mg (1000 mcg) therefore, this will be considered the maximum dose. Table 49 illustrates that with a variance of 30% the all doses are under the maximum safe dose thus the risk of unwanted hypertension, vasoconstriction of tachyarrhythmia is decreased. As the minimum therapeutic dose is not validated or reported this was not examined. However, one could assume that an underdose would not have the desired effect and be repeated at five minute intervals[18] until therapeutic effect is reached, the downside of underdosing and titrating until effect is that this prolongs time to treatment which is related to less chance of survival.

Table 49 - Dosages of adrenaline with ±10%, ±20% and ±30%

Age years	**Weight kg**	**NZRC dose of 10 mcg per kg** -30	-20	-10	10 mcg / kg	10	20	30
2	**14.8**	103.4	118.2	133.0	147.8	162.6	177.3	230.5
3	**17.0**	119.1	136.1	153.1	170.1	187.1	204.1	265.3
4	**19.5**	136.3	155.8	175.3	194.8	214.2	233.7	303.8
5	**22.4**	156.9	179.3	201.7	224.1	246.5	269.0	349.6
6	**25.2**	176.6	201.8	227.1	252.3	277.5	302.7	393.6
7	**28.5**	199.5	228.0	256.5	285.0	313.5	342.0	444.6
8	**32.8**	229.4	262.2	294.9	327.7	360.5	393.3	511.2
9	**37.3**	261.0	298.3	335.5	372.8	410.1	447.4	581.6
10	**41.9**	293.4	335.3	377.2	419.1	461.1	503.0	653.9
11	**47.4**	331.5	378.9	426.2	473.6	521.0	568.3	738.8
12	**53.5**	374.2	427.7	481.1	534.6	588.0	641.5	834.0
13	**57.4**	402.1	459.5	516.9	574.4	631.8	689.2	896.0
14	**61.2**	428.4	489.6	550.8	612.0	673.2	734.4	954.8

The results discussed here will related to the statistics from the test dataset from Statistics NZ (n = 8413) set aside for testing the regression model/equations. This is because the power of 0.8 was not reached with the small sample collected in this study.

On comparison of the WEWW application with the acceptance criteria in section 7.3.10, Table 44, all were met with one exception - the accuracy of the WEWW application. Generally, clinical literature reports the accuracy of weight estimation as ±10% of the actual weight.[19] The reason that the acceptance criteria stated 75% of participants must be ±10% of the actual weight is for comparability with the most accurate weight estimation methods reported in the literature for NZ children. The 75% accuracy was set based on aim of the WEWW application outperforming the Broselow-Luten tape which is the most accurate weight estimation method in NZ [14, 16, 17] and worldwide,[14, 27, 52, 336] often with over 70% of weight estimates reported as being within 10% of actual weight. However, the Broselow-Luten tape is not explicitly endorsed by the NZRC[18] and therefore was not included in the design of this study. NZ dataset related to the accuracy of the Broselow-Luten tape is aging with data collected at least one year before publication.[14, 16, 17] Which begs the question: “is the Broselow-Luten tape still this accurate”?

To compare accuracy a comparison was completed using from the Statistics NZ *test dataset* with a height between 46.0 cm 139 cm (n = 4917) which is the height restrictions when I measured the of most up to date version of the tape. Of the eligible children the Broselow-Luten tape estimated the weight 57.4% of children within 10% of their actual. This shows a considerable (approximately 15-20%) drop in accuracy for Broselow-Luten Tape when compared with previous NZ literature[14, 16] and also illustrates the difficulty comparing current studies against those with ageing data or limited height band of children. With the decrease in accuracy of the non-endorsed weight estimation method and height restrictions in mind, further formal research is required to validate the Broselow-Luten tape and regression models and equations. Future research should also include further validation of weight estimation in an NZ context, with more in-depth investigation and validation of accuracy thresholds such as ±10% and the impact this has on medication dosing and equipment selection. This will guide the amendment of the accuracy threshold set in the acceptance criteria which now seems to high when compared with NZ literature.

A similar issue was found in the comparison of the *Helix* application with the WEWW application. Helix augments the Centre for Disease Control (CDC) and World Health Organisation (WHO) weight-for-age estimates by adding gender and a visual representation of body habitus on a mobile device to estimate the weight of United Kingdom (UK) children.[67] While using both gender and body habitus to improve the accuracy of weight estimation have appeared in previous literature[14, 27, 68, 69] a smartphone representation of a child that can be resized to match body habitus makes this research novel. This study reported that 70.4% of estimates using the Helix application were within 10% of a child’s actual weight, therefore outperforming the WEWW application. A limitation of the study presenting the *Helix* application[67] is that it was tested using an existing dataset that only included children aged 4 to 5 years or 10 to 11 years whereas the WEWW study used a prospective sample of children aged 2 to 14 years. While the *Helix* application accuracy may outperform the WEWW application, the disparity between datasets illustrates the difficulty in successfully comparing these studies. Not only are the ages of children different, utilisation of an existing dataset in the Helix study means the data is static and ageing while the population is evolving. Therefore, further validation of the Helix application is required to ensure results are accurate across age and geographic locations while the WEWW application requires validation with a much larger and diverse dataset. These findings coupled with the decrease in accuracy when the Broselow-Luten tape weight estimate when applied to the Statistics NZ dataset, indicates a more extensive study with more structured sampling is necessary to validate the accuracy of the WEWW application against existing weight estimation methods using the same dataset to allow a more detailed comparison.

The authors of the *Helix* application suggest[67] suggest length-based methods should be considered more accurate and be used instead of the age-based methods for weight estimation yet the *Helix* application that they have developed is through age-based weight estimation. Interestingly an overlay that adjusts to body habitus was considered a part of the WEWW application; however, the researcher did not continue with this as a simpler approach was considered tapping on the head and feet of the child on the smartphone screen. The success of

Helix application[67] which measured ±10% of actual weight for 70% of children in using body habitus to augment age-based weight estimation, has prompted the reconsideration of incorporating this concept into the WEWW application to improve the accuracy of length-based weight estimation as post-doctoral work.

A second study (n = 627) that utilises photogrammetry to measure the length of a child using an artefact. [166] This study evaluates a smartphone application called *Optimizer,* written using the *Java* programming language and deployed on Android mobile devices.[166] *Optimizer* uses a tag that looks like a QR code as a point of reference in the photograph to measure the child. Results show good agreement between the estimated length and measured length of children with a bias of −0.1 (95% CI −0.3–0.2).[166] Conversion of length to weight was via the Kindersicher Tape developed derived using a sample of German children with a height measurement of 47.0 to 143.6 cm or 3 to 36 kg and uses similar ordinal measurements as the Broselow-Luten Tape. The *Optimiser* application mirrors the ordinal categories from the Kindersicher tape using these to give a bias of 11.4 (95% CI 10.6–12.1).[166] This difference illustrates that further research is required investigating the applicability of emerging technology such as the *Optimzer* application to paying particular attention to the multi-ethnic nature of NZ children where adiposity and other demographic characteristics vary widely[70, 294].

The *Optimizer* application[166] faces the same issue as the Broselow-Luten tape and other weight estimation methods, it is limited by height and weight restrictions making comparison difficult. Again, this highlights the need to consider a broader approach to weight estimation, that may be less accurate or a method that might be slightly more accurate but has more constraints around its use. The WEWW application was designed to allow a broader population weight estimates, however, further investigation of the clinical context surrounding the accuracy of weight estimates and the impact they have on treatment is required to guide further and perhaps more targeted weight estimation.

Both regression equations/models outperform the NZRC and St John weight estimates for the Statistics NZ *test dataset* (

Table 50). Still, accurate results are more scattered across methods for the small sample collected for this study which is most likely due to the small sample size (n = 23).. However, with this in mind future research will include validation of the WEWW application with a larger dataset.

Table 50 - Summary of most accurate methods of weight estimation using the Statistics NZ test dataset

Mean Percentage Error		**Limits of Agreement**		**Percentage of children's weights within a given percentage of actual weight**		
				10%	20%	30%
MPE	SD	Diff.	LoA	%	%	%

Ethnicity - 1.1	NZRC 16.7	Ethnicity 5.7	Ethnicity 20.9	Ethnicity 41.1%	Ethnicity 71.6%	All estimation methods 100%

MPE = Mean Percentage Error, SD = Standard deviation, Diff. = Mean difference of Limits of Agreement, Ethnicity represents the regression model/equation that includes ethnicity as a factor, NZRC = New Zealand Resuscitation Council

While overall accuracy favours the regression equations/models that include ethnicity, there are several areas where the accuracy could be improved in post-doctoral work. One way that this could be achieved is through transformation of data to normalise errors using variables such as age and ethnicity. For example, Section 7.3.2 on pages 130 – 137 shows that the regression equations/models were more peaked in younger children and fitted more closely with older children and the opposite was true for existing weight estimation methods (NZRC and St John). These findings correlate with existing literature that test the APLS (NZRC and St John) formula accuracy for children under 10 years that indicates that accuracy decreases as children age.[14-17, 27]. and these may be corrected by either transformation to normalise errors of selection of a more accurate forms of data modelling to predict weight.

The variance of accuracy across reporting methods in

Table 50 shows the need for further investigation of the relationship of the three common reporting methods along with investigation of which of these relates better to the clinical needs of children being resuscitated. Similarly, the common measure of the proportion of weights ±10% of actual weight has yet to be fully validated in literature. [14, 16, 27] Therefore, future work needs to determine and verify the limit of clinical accuracy required in weight estimation.

Even though the user workflow related to weight estimation using the WEWW application was streamlined as a part of this study, one area still to address which could increase accuracy is to locate and minimise areas of error outside of the user workflow. The literature appears to concentrate on the error associated with age or height in weight estimation[27] with emerging literature beginning to address some other demographic factors such as ethnicity.[14, 16] What is not evident in literature yet is the impact of errors induced by technology on weight estimation. A novel mobile application like the WEWW application could introduce new places that error could occur, potentially causing a compounding error. For example, a distinct advantage of photogrammetry, as opposed to traditional weight estimation methods, is that measurement of length in photogrammetry is known to provide better consistency and inter-rater reliability than traditional measures from measurement with a ruler.[194-196] However, the length is later used to derive a child's weight, which illustrates the measurement of length itself is only a small component of the weight estimation process. As with the WEWW application, when length estimation is used in conjunction with other components of a process, other aspects including the conversion of height to weight could be inaccurate and compound error leading to an increase in the error.

With this in mind, Figure 82, illustrates some possible points of error in the weight estimation process.

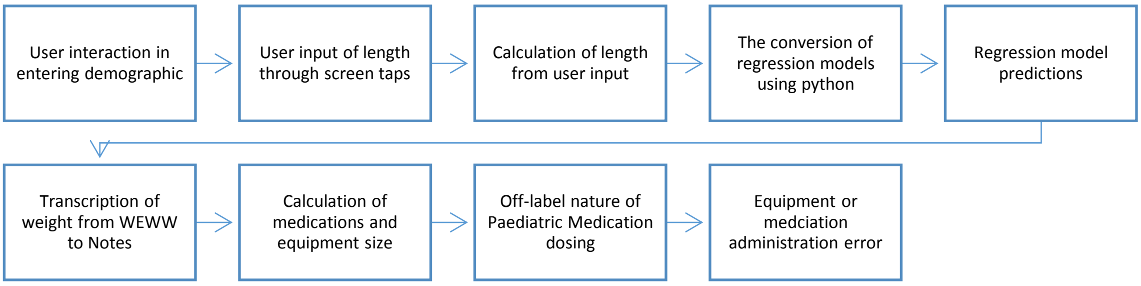


Figure 82 - Potential points of error which relate to weight estimation

Some techniques used in the development of the WEWW application like user-centred and participatory design[337] were included in the software design process to ensure technology-induced user errors are minimal and workflows can be streamlined to meet the needs of the users. The points of error identified in Figure 82 can be easily minimised. For example, functions within the application itself such as calculation of length from the user input. Others may potentially be minimised with user training and experience. For example, ensuring that users enter as much demographic information as possible and practice screen taps to improve the precision of measurements.

One place in Figure 82 already prone to error before the introduction of the WEWW application, is in the calculation of medication dose or equipment size. Medication dose errors are more common in the paediatric environment as prescribing for children is more complex[338] than in adults as paediatric doses vary with weight or body surface area.[4] One study of paramedics showed that this complexity along with fewer paediatric presentations (leading to less experience in treating children) commonly resulted in children receiving doses of medication considered outside of the therapeutic range (dose required to achieve the desired effect).[4] Along with this, some medications that are used in resuscitation have not been tested in children and as a consequence, age-related pharmacodynamics (mechanism of action) and pharmacokinetics (movement of medication around the body e.g. absorption) of these medications are unknown. This means is the optimal dosing is unknown for some resuscitation medications including adrenaline.[66] Incorporating the calculation of drug doses into the WEWW application could remove the potential for error associated with the need to calculate doses from weight or body surface area. The calculation of equipment size and medication doses would be easily added to the WEWW application and from the feedback from those testing the WEWW application (Table 52) in this study, addition of medication calculations is a feature that would be beneficial for clinicians. Some might argue the processes that occur after weight estimation and as such medication dose calculations are outside of the scope of this thesis. However, for future development, optimisation and validation of the WEWW application addressing paediatric doses and prescribing for resuscitation would provide valuable information for clinicians.

The validation process would need to include the examination of medication pharmacokinetics and pharmacodynamics along with the adiposity and body surface area of a child in comparison with resuscitation medication protocols. With this in mind, it seems logical to validate the error in weight estimation literature (±10%) while exploring the effect of resuscitation medication doses so as not to replicate portions of future research unnecessarily.

8.3 Limitations and Future Research

This section looks at the limitations and options for future research and will summarise these at the end of this section.

One limitation of this PhD was related to the literature review (Chapter Two) which did not use a second reviewer of data to minimise reporting bias which is a requirement of the Joanna Briggs Institute (JBI)[85] scoping review protocol. The decision not to have a second reviewer was related to the need for this thesis to be work of a sole author (the PhD student). In subsequent research and application of the JBI protocol, a second reviewer will be included.

A prominent limitation in this study is the geographically constrained as it occurred in one city (Auckland) along with the small sample size of children measured (n = 23). While a larger sample was planned, circumstances outside the researchers control prevented further data collection involving children. In opposition, one could also argue a larger sample is unnecessary as the focus of this PhD is the design and development of the WEWW application with validation being post-doctoral research. However, a larger sample of children would have been optimal as it would have given a more diverse population that allowed for stratification and more in-depth data analysis using demographic characteristics using a separate sample from that used in regression testing for comparison.

Earlier discussions have illustrated that literature is unclear on the number of user testers required and whether data saturation is of importance to this study. Fifteen user testers participated, although one did not return her consent form and data was subsequently not utilised. While more, user testers would have allowed for more diversity and comparison using demographic characteristics including the investigation of WEWW use across disciplines and characteristics like age, gender, workplace, role, and for correlation of TAM results. It is unclear if saturation would be reached, as discussed earlier, it is unclear whether the data would in fact be richer.

Understanding the cognitive load users face is an essential consideration in application design and development.[333] Literature suggests that cognitive load can influence weight estimation during resuscitation [5, 7, 119, 339, 340] yet no research has measured cognitive load in relation to weight estimation in paediatric resuscitation. Tools for the measurement of cognitive load exist, for instance the National Aeronautics and Space Administration (NASA) Task Load Index(TLX) score.[341, 342] Application of these tools to measurement of cognitive load in the weight estimation process during the introduction of the WEWW application into clinical practice would provide valuable data for future research and development of the WEWW application.

One limitation evident in weight estimation literature is that weight estimation solutions are playing "catch up". For example, existing NZ literature was published in 2015 with data collection occurring at least one year before publication and solutions from this data even later.[14, 16]A prime example lag and disparity between research and implementation into practice is related to the origin of the current weight estimation methods endorsed by the NZRC that do not necessarily match the population where they are deployed. For example, the Advanced Paediatric Life Support (APLS) formula recommended by the NZRC[18] and St John Ambulance NZ[36] for children aged 1 to 9 years was first published in the UK and the USA more than 20 years ago and is still in use today.[18, 24, 29] However, the adiposity and body mass of NZ children are changing over time[70, 72, 294] which causes a dilemma in the evolution of weight estimation methods with a real risk of the population changing before dissemination of research of application to clinical practice can occur.

There is no easy solution to the lag between research and implementation of solutions when striving to provide evidence-based solutions in health. One way that would partially address this for the WEWW application is to include learning from real time data where regression models evolve to take population changes into account. Evaluation and implementation of Artificial intelligence (AI) to maintain and improve the accuracy of the WEWW application in alignment with population changes could assist in maintaining the accuracy of the WEWW application. However, further investigation of information privacy, storage and transmission is required prior to addressing this future development.

A limitation with novel software like the WEWW application is that using mobile devices in resuscitation is only just emerging. Limited validated research is available with many solutions focussing on adult resuscitation. Similarly, the two studies that address using mobile technology in weight estimation for paediatric resuscitation[67, 166] require validation and future research to allow application to a broader market. Future research which validates this study alongside existing studies of mobile technology use in resuscitation would allow for better comparison. Furthermore, contacting researchers who are developing similar solutions could lead to international collaboration in future application development.

A similar issue is apparent in non-technology-based weight estimation research. A clinical cut off point of ±10% of actual weight is prevalent as a threshold in weight estimation literature[27] yet this threshold has not been validated in the literature. As shown in Table 6 (section 1.8.1) validation is difficult as many of the medications used in resuscitation are not tested or even recommended for children. Considering the legal and ethical considerations around research of resuscitation drugs in children, the validation of resuscitation medication thresholds may not be possible. However, a thorough systematic literature review on paediatric resuscitation medication dosing may provide some insight that could be applied to weight estimation and therefore the WEWW application.

8.3.1 Environment

The testing of the WEWW application only included indoor user testing that was not in a hospital or resuscitation area. By using multiple indoor testing sites, the WEWW application testing design was more extensive than existing studies[67, 166] that included a static non-resuscitation environment. Inclusion of outdoor locations and the position of the phone on measurement could provide valuable information around the function and usability of the WEWW application. Furthermore, inclusion of more diverse environments in testing could provide more information around the performance of the WEWW application, for example, testing at night versus in the day and good light versus poor light.

8.3.2 Users

Guidance and regulations around application development is limited in New Zealand where topics like secure transmission of data is well documented, however, guidance on other aspects of the design and development of healthcare-related applications is either absent or emerging.[88, 251, 252, 254, 261] Revision and extension of existing legislation that governs the production and use of medical devices is under review and public consultation closed on 19th April 2019 with a new definition of a therapeutic that seems to include the development of software including mobile applications. [343] However, the timeframe in implementation of the new legislation is unknown making the need for explicit development of NZ guidelines or advice for developers of health applications important in the interim. Furthermore, guidance on regulation and distribution of mobile health applications for both the public and healthcare providers could also inform future development of healthcare solutions which use mobile technology including smartphones and wearable devices.

Further work around the decisions and choices related to estimating weight made by the users could provide insight. For example the NZRC guidelines[18] only suggest considering length-based methods of weight estimation if a child “looks obese”. Determining which children look obese is subjective, and therefore consistency of weight estimates may be variable and impact resuscitation treatment. What this shows are the need for further investigation of decision-making concerning weight estimation. As an example, the examination of the relationship between the choice of weight estimation technique with EBP and current guidelines could provide valuable insight into the enablers and barriers clinicians face in providing paediatric resuscitation. The recognition of enablers and barriers could go on to inform future weight estimation application development.

8.3.3 WEWW development

A logical area of improvement to the current WEWW application would be developing a cross-platform solution. Furthermore, investigation of the desirable features that were identified during the user testing process; for example, the addition of calculation of medication dose calculations as well as calculation of equipment size and the kilojoules used for defibrillation. Addition of these features fits well with the current iteration of the WEWW application. However, further research of the applicability of resuscitation medications to children concerning pharmacokinetics and pharmacodynamics needs investigation in parallel with the addition of these features.

One area that the users found difficult was seeing the cross-hair and focus square in the WEWW application in specific environments. Therefore, plans for future development include the investigation of different application colour schemes and automatic change in colour of the cross-hair and focus-square to contrast the environment. Furthermore, even though users did not mention it during testing the contrast of writing and background on the input screens could be improved. One difficulty related to this is designing and application that will adjust to different phone screen sizes, currently the buttons are sized for the smallest phone screen in the Apple iPhone family and investigation of advances in accessibility features for future iterations of the WEWW application may provide a solution.

The need for user input to detect the child also needs to be considered. Automated detection of the child was an initial feature of the WEWW application. However, due to its complexity, this was discontinued as a part of this PhD research and is planned to be continued as future work.

A feature which goes hand in hand with detection of the child is the estimation of the position of the child with correction of any curvature factored into the estimate of their length and ultimately weight. Currently the WEWW application assumes the child is lying flat in a supine position, while this aligns with the best position required to provide optimal resuscitation interventions.[18, 92, 105, 248] If a child is measured in a different position, for example, while curled, the measurement of height and estimate of weight may not be as accurate. Programmatic compensation for this is possible; for example, photogrammetry is used to compensate for curvature in the measurement of rainbow trout using a fixed camera and top-down view.[344] Application of a similar process to weight estimation of a child is challenging due to the variable nature of resuscitation environments and need for a portable camera. For this reason, a limitation of the WEWW application itself is the need for the child to be lying flat. The investigation of object detection and compensation for variance in body position becomes a priority for post-doctoral work.

8.4 Implications for practice

In health informatics, mobile applications are generally designed to inform and improve clinical practice with a focus on safety. WEWW is the first mobile application for weight estimation during advanced paediatric resuscitation that is tailored to the characteristics of NZ children aiming to improve the consistency and accuracy of weight estimation.

Design, development, testing and evaluation has shown that the WEWW application can provide more accurate weight estimation than the existing methods endorsed by the New Zealand Resuscitation Council and St John Ambulance. However, it is not quite obtaining the accuracy of the Broselow-Luten tape which is used widely around the world but not explicitly endorsed in New Zealand. Therefore, the use of the WEWW application could improve the accuracy when guidelines suggest current NZRC or St John age-based methods, however, if used outside of this context caution would be recommended until further validation with a larger and more diverse sample has been completed.

The acceptance or update of the WEWW application seems very likely as the attitude of user testers was positive towards the WEWW application after testing with over 90% of users suggesting the WEWW application was useful, a good idea would make weight estimates more reliable and that there was little risk of harm to patients. It is worth noting that three-quarters of the user testers were ambulance staff and future user testing in a more diverse population of healthcare professionals that work in paediatric resuscitation may allow for more insight into acceptance in other professions. Acceptance into practice by clinicians could, in turn, reduce the ad-hoc changes noted in weight estimation techniques to match population needs and increase the accuracy and consistency of weight estimation while potentially decreasing cognitive load during paediatric resuscitation. With increased accuracy and consistency as well as decreased cognitive load, one could speculate that resuscitation processes may be more streamlined and successful. However, future research to validate this speculation is required.

The WEWW application was the first smartphone-based weight estimation tool to be tested in varying conditions in order to mimic the variable environments faced in the ambulance service and hospital environments. This led to the identification of limitations such as the impact of multicoloured carpets and light-coloured lino. What this means is that the WEWW application works well in certain environments such as on dark coloured surfaces. Therefore, if WEWW were to be implemented without further testing and development around use on patterned surfaces restrictions would need to be placed on use, for example "use consistent coloured surfaces only".

Overall the WEWW application is well placed to estimate the weight of NZ children aged 2 – 14 years during resuscitation, however, there are some restrictions on use:Firstly, the child must be laying on a flat surface they must also be straight (not curled) which should not pose a problem during resuscitation as this is the optimal position when delivering advanced resuscitation. Secondly, until further development of the WEWW application children can only be measured on consistently coloured surfaces and users will need to test the application on light coloured surfaces prior to used. Thirdly, with safety in mind, until WEWW is validated and accepted into national guidelines it must be used with caution and alternative methods of weight estimation need to be available at point of care, such as NZRC formulae and St John tables. Finally, user training and regulation of the WEWW application is still to be developed and until this time adoption into clinical practice is not recommended.

8.5 Summary of Future Work

While the regression equations/models within WEWW application has shown to be more accurate than existing weight estimation methods in NZ there are a number of ways that that future development and research can be enhanced.

8.5.1 Feature requests and UI enhancements

Firstly some feature requests emerged during user testing that will be investigated in post-doctoral development of the WEWW application. These included automatic detection of the child or adding an overlay to assist with detection of the child. This could also represent body habitus and implement the automatic calculation of drug doses based on the weight estimate. Along with the addition of these features a multi-platform WEWW application is planned.

Some enhancements to the UI could be made based on information collected during user testing. This predominantly includes changes to the user interface to make this more easily read and used, for example, investigating accessibility features to improve visibility such as adjusting the contrast of writing and buttons with their backgrounds and adaptation of the cross-hair to contrast the background. These developments could be informed design of a more structured user testing plan that included, indoor and outdoor environments as well as fixing of the test harness to capture light levels and the position of the mobile device for each weight estimate.

8.5.2 Technology Induced Errors

The investigation of technology induced errors has begun in this study with analysis of the camera versus stadiometer height measurements. However, there are many other areas in the use of technology that could produce errors such as user input, user demographics and environmental factors. A logical place to start is to investigate the relationship of technology induced errors with time to treatment, on the case of the WEWW application, gaining a successful weight estimate. Detailed research of these factors could decrease time to weight-estimate and inform future development of the WEWW application.

8.5.3 Improving the fit of regression models/equations

Analysis of the distribution of error for the regression models designed n this study showed that adjusting the distribution of error based on variables such as age and ethnicity could improve fit of the regression models. Therefore, post-doctoral work includes the investigation of the best ways to transform data to minimise distribution of error include alternative ML models (such as neural networks).

8.5.4 Related future research to inform future development of the WEWW application

Further research related weight estimation could inform future design, development, testing and deployment of the WEWW application. Several thresholds require validation:

- weight estimation accuracy is ±10% of a child's actual weight valid
- safe parameters of resuscitation medications for children to achieve therapeutic effect
- review WEWW application acceptance criteria of 75% of weight estimates be within 10% of actual weight

8.5.5 Decision making processes

Studies of decision making related to weight estimation in paediatric resuscitation are not evident in literature. Therefore, the relationship of cognitive load with paediatric weight estimation in resuscitation and the use of the WEWW application requires investigation. Alongside this research into the clinician decision making regarding the choice of weight estimation method, the use of policy and EBP with any subsequent ad-hoc changes to weight estimations would provide valuable insight into streamlining weight estimation both in general and within the WEWW application.

8.5.6 Documentation, policy and training

The production of documentation to support the WEWW application along with appropriate training and regulation/legislation needs to be addressed. This also includes working with the Health Informatics community in the development of guidelines for software developers in the design and development of applications used in healthcare.

8.5.7 Dissemination of information

An important part of the adapted DSR model used in this research is dissemination of both the WEWW application and related publications. Once the future work listed above is complete an adoption plan will be produced including introduction of the WEWW application to the users/industry along with publications. Currently three publications are planned, the first on the adapted DSR model used in this research, the second introducing the WEWW application and outlining the development and the third a comparison of accuracy with existing weight estimation techniques.

8.6 Reflection

This reflection illustrates challenges and my associated learning during the completion of this PhD. It does not include any academic information that relates to the PhD but discusses my journey as a clinician, software developer, student and an academic researcher in completing this study.

8.6.1 Structure up front

When I started this PhD, I had some experience in research. However, this was limited to clinical trials, usually comparing outcomes or devices. I felt comfortable in the structured environment where there was a clear path through from the beginning to the end of the research. The Design Science Research (DSR) the process selected for this PhD was fluid. This meant that while there was a framework no set path to completion was obvious. I needed to be comfortable with having no obvious endpoint at the beginning of my research. The comfort arrived when I compared DSR with my job as an educator. I had unknowingly used DSR to evolve the teaching and learning I provide for many years as I was consistently trying new things, tweaking these, looking for evidence and evaluating them. Similarly, in education I accepted the failure of ideas as progress yet initially had difficulty translating this into the research world. Comparing my approach to delivery of teaching and learning with DSR broadened my thinking and from this time the value of the DSR methodology was apparent and allowed the adaptability required in implementing this research method.

8.6.2 A real world problem

An early challenge was that this research was designed to solve a problem yet was also my path to gaining a qualification. While many students are "allocated" a PhD topic by their supervisor, I arrived with one as well as a potential solution that I saw as the endpoint of this research. The dilemma in this situation relates to my role of expert clinician versus that of a researcher. As my PhD progressed, I realised that quality and the process of research mattered as much, if not more, than the end result. Realising this and being able to articulate the importance of the research process is knowledge that I can carry through to my academic career and pass on to future students that I supervise.

The above reflection has outlined a small selection of my learning throughout my PhD journey along with some valuable lessons that I can carry into my future career.

8.6.3 Novice to expert

One of the first challenges I encountered at the beginning of this PhD was a conflict between the mindsets that I required as a clinician and a computer scientist. Furthermore, I was attempting to adopt the ways of knowing, doing and being an expert clinician and applying these to a problem that required an approach that wasn't natural in a clinical environment. Or in other words, being an expert nurse in the novice computing and mathematics research world.

While both disciplines are renowned for problem-solving, and both views have value in finding appropriate solutions. The real learning was to realise that being an expert clinician as well as a novice software developer and researcher were not mutually exclusive and therefore valuing the components of each at the right time was vital in moving forward.

Since this realisation, I have come to value the differences between both professions. I have found myself becoming a bridge between the clinical, academic and computing worlds while earning respect, being invited for consultation and being a part of guiding nursing informatics policy and curriculum development nationally. This transformation shows the evolution from novice research to respected academic.

8.7 Conclusion

This thesis has outlined the design and development of an offline, native, modular, mobile application that allows healthcare professionals to estimate the weight of a child during advanced resuscitation in multiple environments. Weight estimates are based on the demographic characteristics and length of the child measured using augmented reality (AR) on a mobile device.

An adapted design science methodology was followed to allow structure and rigour in this research. During design, acceptance criteria were formulated and enhanced based on findings that emerged throughout this research. An analysis of user workflows informed the simplification of the weight estimation process.

Regression models/equations were developed using a large NZ dataset which was split into two random subsets (training and testing). A smaller dataset was collected for this study measuring children using a traditional scale and stadiometer. Children were then measured WEWW application to give a comparison, which was primarily used to identify technology induced error between camera and stadiometer height measurements.

The discussion critiquing the WEWW application design, development and testing while provided links between these and their clinical application to ensure the focus remained on estimation of weight for a child requiring resuscitation while presenting a solution that applies to multiple contexts. The limitations of this research and future work is presented.

While most of the acceptance criteria were met; one was not met the WEWW application does not match the accuracy of over 75% of weight estimates within 10% of actual weight. However, the WEWW application does outperform the current weight estimation techniques endorsed by the NZ Resuscitation Council and St John NZ making this a viable option for use in NZ. However, it is worth noting this recommendation is made with the knowledge that further optimisations are likely to improve the accuracy of weight estimates.

In conclusion, is the first mobile application to implement measurement using AR to predict the weight of children in resuscitation. It meets all but one of the acceptance criteria, however, in light of the decrease in accuracy of some existing weight estimation techniques the requirement for 75% of weight estimates within 10% of actual weight may need revision. The regression models/equations outperform the weight estimation methods currently endorsed by the New Zealand Resuscitation Council and St John NZ, however it is likely that future development including of transformation of data to normalise the errors based on age and ethnicity could further improve the accuracy of the WEWW application.

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10 Appendices

10.1 Appendix A – Statistics New Zealand – Lead Institution License

Statistics New Zealand
Tatauranga Aotearoa

Statistics New Zealand
Confidentialised Unit Record File (CURF)
Lead Institution Licence

Between **Statistics New Zealand**

and **Auckland University of Technology**

1 Definitions

1.1 Project name **CURF2017-29 Weight Estimation Without Waiting**

1.2 In this Agreement, unless the context otherwise requires:

"CURF" means the physical media and/or electronic files and the data and documentation they contain for the following.:

New Zealand Health Survey 2011/12
New Zealand Health Survey 2012/13 Children
New Zealand Health Survey 2013/14
New Zealand Health Survey 2014/15
New Zealand Health Survey 2015/16

"Institution" means:

Auckland University of Technology

2 Period

2.1 The CURF will be licensed from 02/10/2017 to 02/10/2018, unless terminated in accordance with clause 8.

2.2 If the research project lasts beyond the date specified in the Agreement, a further period may be renegotiated if mutually agreed in writing.

3 Grant of Access

3.1 The CURF(s) will be used only for the statistical purpose specified in Schedule A of this Agreement.

Version 2, February 2014

3.2 The CURF(s) may only be accessed by the researcher(s) specified in Schedule A, and who have signed a Researcher Undertaking for the project.

3.4 Further researchers may be added to Schedule A, by written agreement between the parties, and subject to the terms of the Agreement. This must occur before the researcher uses the CURF.

3.5 The Institution will notify Statistics New Zealand if any researcher authorised to access the CURF(s) ceases to be a member of the research project specified in Schedule A or if the Institution rescinds that authorisation.

3.6 The Institution is authorised to copy the CURF(s), so that each researcher working on the project has one copy, subject to clause 7.

3.7 Should the researcher(s) express concerns to the Institution about the quality of the CURF(s), the Institution agrees to notify Statistics New Zealand immediately and not to publicise their concerns.

4 Payment

4.1 Access to CURF(s) for this project is free.

5 Confidentiality and Security

5.1 The Institution will take reasonable actions to ensure that researchers authorised to access the CURF(s) make use of the CURF in accordance with the conditions specified in the Researcher Undertaking, including only using the CURF(s) for reporting aggregate information, not attempting to identify individual respondents from the CURF(s) and keeping the CURF and any copies of information from the CURF secure. This clause extends to those named researchers on the project who are not employees of the Institution.

5.2 Should a breach of this confidentiality and security clause take place, , the Institution will notify Statistics New Zealand immediately and discuss what measures will be taken to remedy the breach of this Agreement.

6 Liability

6.1 Statistics New Zealand shall not be liable for any misuse or consequential risk or loss resulting from the use of, or reliance on, the CURF.

6.2 While all reasonable care and diligence has been exercised in compiling the data in the CURF, no warranty is given by Statistics New Zealand as to the accuracy and comprehensiveness of the information.

7 Acknowledgements

7.1 The Institution will ensure that the following acknowledgement is included when publishing any output and/or documentation in which information was analysed or gathered from the CURF(s).

"Access to the data used in this study was provided by Statistics New Zealand under conditions designed to keep individual information secure in accordance with requirements of the Statistics Act 1975. The opinions presented are those of the author(s) and do not necessarily represent an official view of Statistics New Zealand."

8 Termination

8.1 Either party may terminate this agreement where thirty (30) days notice is given in writing to the other party.

8.2 Statistics New Zealand may, by written notice to the other party, terminate this agreement immediately if the other party breaches this Agreement and fails to remedy the breach within the time agreed between Statistics New Zealand and the researcher(s).

8.3 Regardless of who initiates the termination or cancellation, the process will not be complete until the terms of clause 9 Closure has been completed.

9 Audits

9.1 The Institution agrees that Statistics New Zealand can carry out audits of researchers who have access to the CURF(s) to confirm that the conditions of this agreement and the researcher undertaking are being followed.

9.2 If selected for an audit the Institution agrees to grant permission for Statistics New Zealand to visit the research site(s) and speak with the researchers.

10 Delivery

10.1 The CURF(s) will be provided to the researcher(s) once this Agreement has been completed and signed by the authorised representative of the Institution, and the completed and signed Researcher Undertaking(s) have been received by Statistics New Zealand.

11 Copies of signed Licence Agreement

11.1 Please retain one signed copy of this Agreement for your records and return the second signed copy to Statistics New Zealand.

I hereby acknowledge the above terms and conditions of the CURF Licence Agreement and I have the authority to sign on behalf of the Institution.

Name: Sally Britnell

Position: Lecturer

Signature: SBrtnell

Date: 27/9/17

Discussed with Arvind who stated it was ok for researcher to sign on behalf of AUT.

Signed on behalf of Statistics New Zealand by:

Name: **Natalie Keyes**

Position: **Customer Liaison Manager, Integrated Data**

Signature: NKeyes

Date: 25th September 2017

Version 2, February 2014

10.2 Appendix B – Verification of Māori consultation

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

School of Clinical Sciences
Mātauranga Māori Committee

Verification of Māori Consultation

This document provides verification that the research project named below was discussed with the School of Clinical Sciences Mātauranga Māori Committee, Auckland University of Technology. Specific comments and recommendations are indicated below.

Research Title: Weight estimation without waiting.		
Researcher(s): Sally Britnell (PhD Student / Nursing), Dave Parry (Supervisor / Computing and Maths), Gael Mearns (Supervisor / Nursing), Graham Howie (Supervisor / Paramedicine)		**Date:** 10/5/18
Discussion Areas	**Discussed**	**Comments/ Recommendations** (see next page)
Whakapapa: Relationships		
Researcher experience in field		C1
Consultation with local stakeholders		R3, R5
Consenting process		R2, R5
Clarity of data usage		C3, C4, C5
Dissemination of findings		
Benefits to participants		
Tika: Validity of the research		
Clear purpose of project		C2
Relevance to Māori		R4
Likely outcome for participants, communities, other stakeholders		
Participant recruitment methods		R2
Māori involvement in project (participants, researchers, etc.)		
Manaakitanga: Responsibility and respect		
Participants' access to appropriate advice		C5
Participants treated with dignity and respect		C5, R1
Privacy and confidentiality		C5
Whānau support		
Transparency of research process		
Mana tangata: Power & Authority		
Reciprocity (acknowledgements, compensation, gifts)		
Risks of participation identified		
Ownership of outcomes		
Informed consent process		

Comments

1. The applicant is a paediatric nurse. Her research project is a pilot study being undertaken as part of her PhD. The study has developed out of work she did for her Masters degree.
2. In order to prescribe medication accurately for a child it is necessary to know the child's weight. Formulae provided by the Resuscitation Council have been found to be accurate in only 43% of the time. Also, there is often insufficient time during a resuscitation procedure to accurately weigh children. The applicant considers that a more tailored weight estimation is of particular importance across ethnicities because ethnicity has a significant impact on weight in children.
3. The applicant is designing a mobile application (app) that can calculate weight more quickly, and more accurately, than can be achieved with the method in current use. The app uses New Zealand height and weight data for children from the Ministry of Health dataset, and regression modelling to calculate an appropriate weight. The app will be used in children from toddler stage to age 14.
4. The data entered into the app will be gender, age and ethnicity (options as used in the NZ census), and then the operator will use the app's augmented reality capabilities to calculate the child's length/height. The app is for calculation purposes only and any data or images will not be stored. The applicant advised that she will be looking into including multi-ethnic calculations during the app's development.
5. Fifty (50) children will be sought for testing. The children will have a parent or caregiver present during the testing procedures. Pictures will not be taken, and no clothing will be removed during the testing process. The app will be used to measure the child while they are prone, and a weight estimation will be made. The child's actual height and weight will then be measured using a stadiometer and scales. The tester will not say the weight out loud; she will write it down on a piece of paper and give it to the parent/caregiver.
6. While the usability of the app will be tested with children, the feasibility of the app will be tested with a diverse group of health professionals including both nurses and doctors.

Recommendations

1. The child and the parent/caregiver should be told that the stadiometer will lightly touch the top of the child's head, and that the stadiometer is cleaned between the measuring of each child.

2. The use of social media as a means of seeking participants may reduce the ethnic diversity of the participant group. It is recommended that the applicant make approaches to schools, as she did for her Masters degree research – aiming for schools that are known to have an ethnically diverse population. Going back to some of the schools she worked with previously may produce a good level of participation and encourage an ongoing relationship.

3. The applicant mentioned that she has a working relationship with St John New Zealand at their Ellerslie branch, but she would need to get a site agreement to be able to talk to their staff about participating in the study. The Committee recommended that Tahuhu, the the St John's Māori liaison group, may be worth approaching – and perhaps also the Parenting Centre in Ellerslie. Approaching a School Holiday programme was also suggested.

4. While the focus of the applicant's PhD is the development of the technology, the opportunity to gather ethnically diverse data during the testing process is also very important. If a larger sample size could be collected it would allow the applicant to validate the app in a population reflecting the ethnic diversity of New Zealand. This is important because ethnicity has a significant impact on weight in children.

5. If the recruitment is undertaken through a school or other organisation, the Committee recommends that the applicant offer to return later to disseminate the results in person. The Committee may be able to approach Wiri Central School on the applicant's behalf.

Please contact the Committee's Administrator Eleanor Fearn at eleanor.fearn@aut.ac.nz if you have any questions about this feedback.

You may be contacted in 12 months' time for feedback about the process and the usefulness of these comments and recommendations to your project.

Signature: G S Mawston Date: 10 May 2018

Grant Mawston
Mātauranga Māori Consultation Committee

10.3 Appendix C – Ethics Approval

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

18 June 2018

Dave Parry
Faculty of Design and Creative Technologies

Dear Dave

Re Ethics Application: **18/213 Weight estimation without waiting**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 18 June 2021.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: , sally.britnell@aut.ac.nz; gael.mearns@aut.ac.nz; Graham Howie

10.4 Appendix D – Information sheets and consent forms

10.4.1 Child under 11 years Information sheet and assent form

Information for Children

WEWW Study

Supervisor: Dave Parry

Researcher: Sally Britnell

What is this study?

This study compares the weight and height of children in Auckland with methods used to estimate children's weight in an emergency department or ambulance.

Why do we need this study?

In an emergency we may need to guess a child's weight to help them. This study will make sure that weight estimation methods work for children in New Zealand.

What do I need to do?

- You will need to remove any heavy outer clothing (such as jackets and Jerseys) as well as their shoes.
- Sally will weigh you using scales that you stand on.
- She will measure your height (laying down and standing up).
- Weight and height are private and will not be said out loud.
- Sally will write your height and weight on an iPad or computer.
- You can ask questions at any time.

What if I don't want to take part?

If you do not want to take part, please tell your parent or Sally.

Family are invited to be present while their child's height and weight are measured.

How can families help?

By allowing you to be weighed and measured in this study.

If you and your family are happy to help your parent / guardian needs to consent electronically and instructions to complete this have been emailed to them.

What if we have questions?

Children can ask their parents any questions about this study or Sally when she is at your school.

Questions can also be asked by phone or email:

Researcher:

Sally Britnell:
921 9999 ext 7539
Sally.britnell@aut.ac.nz

Ethics Approval gained from the AUT Ethics Committee on XXX
(Approval number XX/XX)
Child information Sheet (Version 2, XXX)

Who are you?

Please write your name?

____

Do you have any questions?

Write any questions you have here?

____

____

____

____

____

____

I want to take part!

Please colour in this face if you do want to have your weight and height measured today:

YES

I don't want to take part!

Please colour in this face if you don't want to have your weight and height measured today:

NO

I don't know if I want to take part!

Please colour in this face if you don't know or have questions?

MAYBE

10.4.2 Child over 10 years information sheet

TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Child Information Sheet (> 10 years)

Date Information Sheet Produced:

22nd May 2018

Project Title

Weight estimation without waiting

An Invitation

My name is Sally Britnell, I am a lecturer at AUT university and previously a Nurse in the Children's Emergency Department at Starship Hospital. I am doing some research and would like you to participate.

What is the purpose of this research?

This study will test a smartphone application to measure your length and predict your weight.

How was I identified and why am I being invited to participate in this research?

Your parent or guardian has indicated you may like to participate.

How do I agree to participate in this research?

Ask your parent to contact Sally who will arrange a meeting to answer any of your questions and get your permission to measure your height and weight.

You can choose whether you agree to participate in this research. You can decided not to continue at any time. If you choose not to continue you can decide if your height and weight are included in the study. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Sally will negotiate a time and place with your parent or guardian. She will ask you to provide your age, gender and main ethnicity of your child and then ask that your child remove any heavy outer clothing and their shoes, will weigh your child and then measure their height laying and standing. After this, she will explain the smartphone application in more detail, allow each child to ask further questions and then use this to measure the child and estimation their weight. No photograph is taken during this process and only weight and height data will be recorded at this time.

What are the discomforts and risks?

Potential for stigma due to verbalisation of weight or height measurements.

How will these discomforts and risks be alleviated?

Privacy will be maintained at all times and no weight or height measurements will be stated out loud to decrease the risk of discomfort and stigma to each child.

What are the benefits?

Children throughout New Zealand will benefit from participation in this study. This application could potentially change practice by increasing the accuracy of weight estimation in paediatric resuscitation. The development of this application will inform practice in medical treatment of children in New Zealand by allowing accurate individualised medical treatment during paediatric resuscitation.

How will my privacy be protected?

Privacy will be maintained at all times and no weight or height measurements will be stated out loud to decrease the risk of discomfort and stigma to each child. All height and weight data will be kept separately to your contact details and both will be identified by a random number.

What are the costs of participating in this research?

The cost of participating is giving 20 - 30 minutes of time.

What opportunity do I have to consider this invitation?

Once you have expressed interest and been provided with information sheets it is expected that we meet with you within a month. To initiate participation please contact Sally, who will arrange a time to meet to answer any questions you have, gain your consent to participate and facilitate application testing and feedback.

Will I receive feedback on the results of this research?

Please indicate whether you would like to receive a summary of the research findings on completion of this study in the consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dave Parry, dave.parry@aut.ac.nz, 921 9999 ext 8918.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Sally Britnell, sally.britnell@aut.ac.nz, 9219999 ext 7539

Project Supervisor Contact Details:

Dave Parry, dave.parry@aut.ac.nz, 921 9999 ext 8918

Approved by the Auckland University of Technology Ethics Committee on 18th June 2018 AUTEC Reference number 18/213

10.4.3 Child over 10 years assent form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Assent For for Children over 10 years

Project title: ***Weight estimation without waiting***

Project Supervisor: ***Dave Parry***

Researcher: ***Sally Britnell***

○ I have read and understood the sheet telling me what will happen in this study and why it is important.

○ I have been able to ask questions and to have them answered.

○ I understand that I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.

○ If I stop being part of the study, I understand that then I will be offered the choice between having any information that that other people can know is about me removed or letting the researcher keep using it. I also understand that sometimes, if the results of the research have been written, some information about me may not be able to be removed.

○ I agree to take part in this research.

Participants signature: ....

Participants Name: ....

Participant Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 18th June 2018 AUTEC Reference number 18/213

Note: The Participant should retain a copy of this form.

10.4.4 Parent information Sheet

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Parent Information Sheet

Date Information Sheet Produced:

22nd May 2018

Project Title

Weight estimation without waiting

An Invitation

My name is Sally Britnell, I am a lecturer at AUT university and previously a Nurse in the Children's Emergency Department at Starship Hospital. I am conducting research and would like to invite you and your child to participate.

What is the purpose of this research?

This study will test the accuracy of smartphone application used to estimate the weight of a child intended for use in paediatric resuscitation / emergencies.

How was I identified and why am I being invited to participate in this research?

You have resonded to an advertisment suggesting your child could participante in this research.

How do I agree to participate in this research?

You will have already replied to the advertisement asking for participants. At this time Sally will arrange to provide you with further information about the study. After reading this contact Sally who will arrange a meeting with you and your child to answer any questions and gain your consent and the ascent of your child to participate.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Sally will negotiate a time and place which suits you to test the application with you and your child. She will ask that your provide age, gender and main ethnicity of your child and then ask that your child remove any heavy outer clothing and their shoes, will weigh your child and then measure their height laying and standing. After this, she will explain the smartphone application in more detail, allow each child to ask further questions and then use this to measure the child and estimation their weight. No photograph is taken during this process and only weight and height data will be recorded at this time.

What are the discomforts and risks?

Potential for stigma due to verbalisation of weight or height measurements.

How will these discomforts and risks be alleviated?

Privacy will be maintained at all times and no weight or height measurements will be stated out loud to decrease the risk of discomfort and stigma to each child.

What are the benefits?

Children throughout New Zealand will benefit from participation in this study. This application could potentially change practice by increasing the accuracy of weight estimation in paediatric resuscitation. The development of this application will inform practice in medical treatment of children in New Zealand by allowing accurate individualised medical treatment during paediatric resuscitation.

How will my privacy be protected?

Privacy will be maintained at all times and no weight or height measurements will be stated out loud to decrease the risk of discomfort and stigma to each child. All height and weight data will be kept separately to your contact details and both will be identified by a random number.

What are the costs of participating in this research?

The cost of participating is giving 20 - 30 minutes of time.

What opportunity do I have to consider this invitation?

Once you have expressed interest and been provided with information sheets it is expected that we meet with you within a month. To initiate participation please contact Sally, who will arrange a time to meet to answer any questions, gain your consent to participate and facilitate application testing and feedback.

Will I receive feedback on the results of this research?

Please indicate whether you would like receive a summary of the research findings on completion of this study in the consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dave Parry, dave.parry@aut.ac.nz, 921 9999 ext 8918.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Sally Britnell, sally.britnell@aut.ac.nz, 9219999 ext 7539

Project Supervisor Contact Details:

Dave Parry, dave.parry@aut.ac.nz, 921 9999 ext 8918

Approved by the Auckland University of Technology Ethics Committee on 18th June 2018 AUTEC Reference number 18/213

.

10.4.5 Parent consent form

Parent Consent Form

Project title: ***Weight estimation without waiting***

Project Supervisor: ***Dave Parry***

Researcher: ***Sally Britnell***

○ I have read and understood the information provided about this research project in the Information Sheet dated 18th June 2018.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I agree for my child to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Child's Full Name : ....

Parent's signature: ....

Parent's full name: ....

Parent's Contact Details (if appropriate):

Email :……………………………………………………………………………………………

Phone: …………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 18th June 2018 AUTEC Reference number 18/213

Note: The Participant should retain a copy of this form.

10.4.6 Healthcare professional information sheet

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Healthcare Professional Information Sheet

Date Information Sheet Produced:

22nd May 2018

Project Title

Weight estimation without waiting.

An Invitation

My name is Sally Britnell, I am a lecturer at AUT university and previously a Nurse in the Children's Emergency Department at Starship Hospital. I am conducting research on weight estimation in resuscitation and would like to invite you to participate.

What is the purpose of this research?

This study will test the usability of a smartphone application to estimate the weight of a child from a photograph.

How was I identified and why am I being invited to participate in this research?

You were invited via advertisment to participante in this research. It is important that the potential users of this smartphone application contribute to the design and feedback from healthcare professions on usability is an important part of this process.

How do I agree to participate in this research?

You will have already replied to the advertisement asking for participants. At this time Sally will arrange to provide you with further information about the study. After reading this contact Sally who will arrange a meeting with you to answer any questions and provide the opportunity to use the mobile application and give your feedback.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

Sally will negotiate a time and place which suits you to test the application and bring the smartphone to you. She will watch you use the application to measure an object and take notes during this process. On completion you be asked to provide feedback on the usability of the application via a survey.

What are the discomforts and risks?

Using this application may provoke thoughts and feelings related to previous resuscitation events.

How will these discomforts and risks be alleviated?

Should this occur, the confidential counselling service offered by your employer through the Employee Assistance Programme (EAP) are available to you, information regarding accessing these is available on the intranet at your organisation.

What are the benefits?

Children throughout New Zealand will benefit from participation in this study. This application could potentially change practice by increasing the accuracy of weight estimation in paediatric resuscitation. The development of this application will inform practice in medical treatment of children in New Zealand by allowing accurate individualised medical treatment during paediatric resuscitation.

How will my privacy be protected?

Your privacy will be maintained, your name and email address will be collected in case we need to contact you to clarify information provided. However this will be separate from data that is used for analysis thus maintaining your privacy.

What are the costs of participating in this research?

The cost of participating is giving approximately 20 minutes of time.

What opportunity do I have to consider this invitation?

Once you have expressed interest and been provided with information sheets it is expected that we meet with you within a month. To initiate participation please contact Sally, who will arrange a time to meet to answer any questions, gain your consent to participate and facilitate application testing and feedback.

Will I receive feedback on the results of this research?

Please indicate whether you would like receive a summary of the research findings on completion of this study in the consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dave Parry, dave.parry@aut.ac.nz, 921 9999 ext 8918.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Sally Britnell, sally.britnell@aut.ac.nz, 9219999 ext 7539

Project Supervisor Contact Details:

Dave Parry, dave.parry@aut.ac.nz, 921 9999 ext 8918

Approved by the Auckland University of Technology Ethics Committee on 18th June 2018 AUTEC Reference number 18/213

10.4.7 Healthcare professional consent form

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Healthcare Professional Consent Form

Project title: ***Weight estimation without waiting***

Project Supervisor: ***Dave Parry***

Researcher: ***Sally Britnell***

- O I have read and understood the information provided about this research project in the Information Sheet dated 18th June 2018.
- O I have had an opportunity to ask questions and to have them answered.
- O I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.
- O I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- O I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- O I agree to take part in this research.
- O I wish to receive a summary of the research findings (please tick one): YesO NoO

Participants signature: ....

Participants full Name: ....

Participants Contact details (if appropriate):

Email :……………………………………………………………………………………….

Phone: ……………………………………………………………………………………….

Date:

Approved by the Auckland University of Technology Ethics Committee on 18th June 2018 AUTEC Reference number 18/213

Note: The Participant should retain a copy of this form

10.4.8 Advertisement for child participants

We are looking for children to assist in testing a smartphone application which estimates weight of a child in an emergency situation.

Children will have their height measured and will be weighed on a traditional scale while wearing light clothing. They will then be measured using the smartphone application.

Further information available at the following links:

- *Parent Information Sheet <http:// …>*
- *Child > 11 years Information Sheet <http:// …>*
- *Child < 11 years Information Sheet <http:// …>*

If you or your child would like further information or are able to participate please contact XXX on XXX xn XXX, or email XXX

10.4.9 Advertisement for healthcare professionals

We are looking for children to assist in testing a smartphone application which estimates weight of a child in an emergency situation.

Children will have their height measured and will be weighed on a traditional scale while wearing light clothing. They will then be measured using the smartphone application.

Further information available at the following links:

- *Parent Information Sheet <http:// …>*
- *Child > 11 years Information Sheet <http:// …>*
- *Child < 11 years Information Sheet <http:// …>*

If you or your child would like further information or are able to participate please contact XXX on XXX xn XXX, or email XXX

10.5 Appendix E – User testing results

10.5.1 Adapted thematic analysis

Table 51 - The following table is an adapted thematic analysis of the user observation and verbal responses of the user testers.

	Data collection method	
	Think Aloud n	**Observation n**
Positive Comments		
Easy or straightforward to use	2	
Useful	2	
Systematic to use or systematic testing by user	1	1
Bugs		
Age doesn't show up	1	
Initial crash on swipe before click	1	
Feature Requests		
Add drug information	1	
Grid overlay for the person being measured	1	
Manipulation of the WEWW application		
Attempted other phone gestures such as swipe	1	3
Very hesitant using smartphone gestures		1
Tapped crosshair rather than anywhere on screen		1
Wanted cross stationary rather than AR	1	
Aim / AR Related - Tricky	2	
Stood still rather than moving around using AR		2
Environment		
Measured in a noisy environment		1
Measured in a quiet environment		5
Measured in a crowded environment		1
Needed to measure through objects		1
Light background made crosshair difficult or dark background might be easier	5	5
Multi-coloured background pattern made crosshair difficult to see	1	3
Concern		
Public might wonder what we are doing	1	
Don't need anything else as have St John procedures with formula. Quoted incorrect formula.	1	
User Characteristics		
No AR experience and all over 40 years of age		5
Wears reading glasses difficulty focusing on screen meaning more moving and tilting		2
Slow in using the WEWW application		1
Wanted to keep playing with the application after 5 minutes		1

Table 52 - User testing, observation and Think-aloud results with demographic characteristic

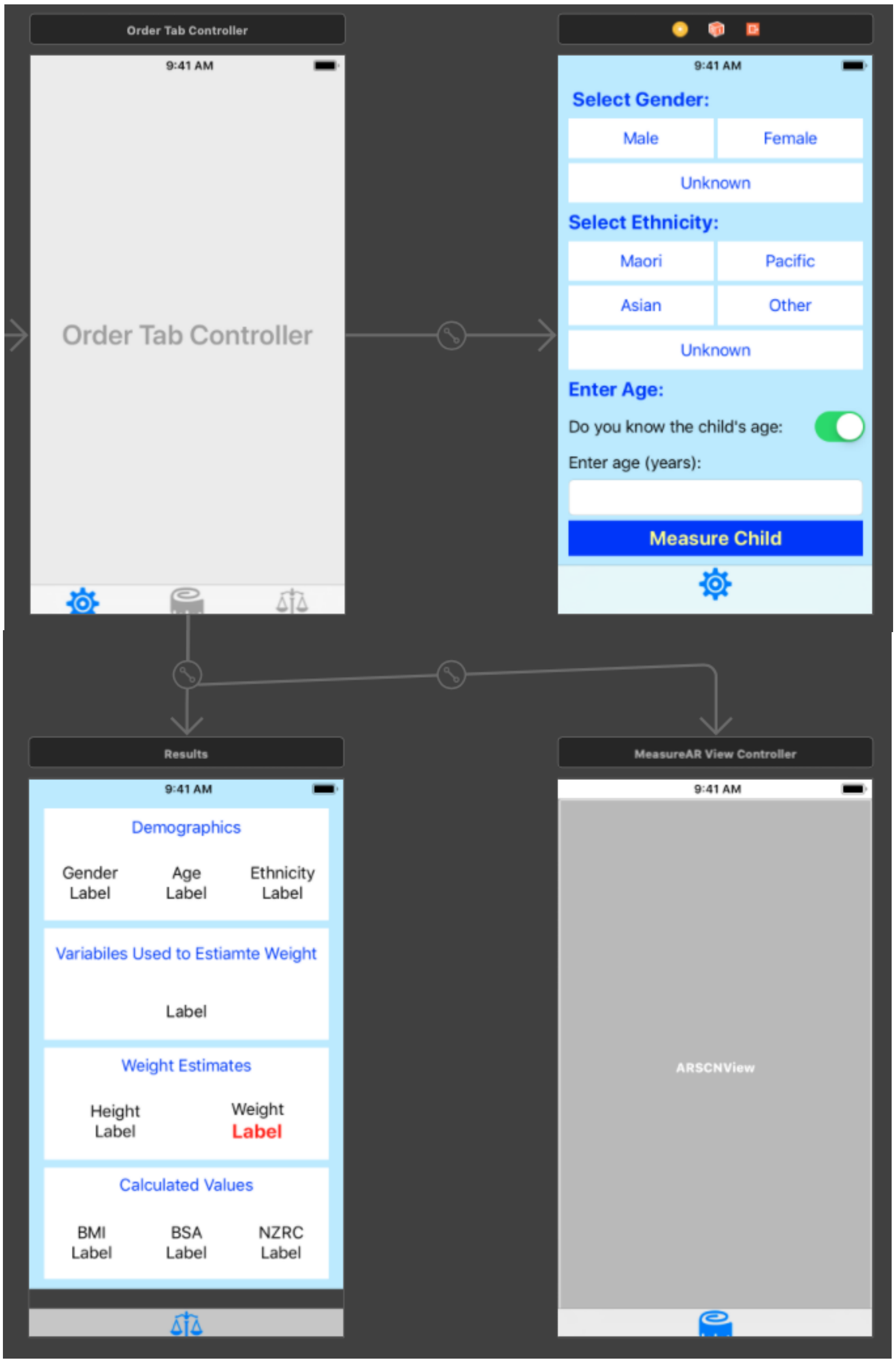
#	Consent	Survey	Qualifications / Role	Age	Successful Measure	Regularly uses smartphone	Experience using AR	Observations	Environment	Experience / Comments
1	✓	✓	AO	50 - 59	✓	✓	✗	Difficulty manipulating AR. Very close to the phone/patient when looking for a solid square rather than moving around. Wears reading glasses.	Light lino – quiet environment.	"Difficult to see the yellow square on white background"
2	✓	✓	AO	20 - 29	✓	✓	✓	No difficulty manipulating UI or weight estimation process.	Light lino – quiet environment.	"easy and systematic"
3	✓	✓	RN	30-39	✓	✓	✓	Only difficulty witnessed was user thought she had to tap in the target square rather than any place on the screen.	Hard wood floor. Crowded environment needed to measure through objects.	"The only part that was confusing for me was age doesn't show up. "Currently and lining up the camera to measure kids' height was tricky initially but this I feel would improve with familiarity". "I found it straight forward to use".
4	✓	✓	AO	40 – 49	✓	✗	✗	Slow to use, not aware of smartphone gestures.	Light lino – quiet environment.	"more useful if drug information was included", "Yellow and green hard to see against white".
~~5~~	Not included in statistics as consent missing		~~RN~~	~~40 – 49~~	~~✓~~	~~✓~~	~~✓~~	~~No difficulty manipulating UI or weight estimation process.~~	~~Multi-coloured environment with people walking around, noisy.~~	~~"the application was useful".~~
6	✓	✓	AO	20-29	✓	✓	✓	No difficulty manipulating UI or weight estimation process. Wanted to keep playing after time was up.	Light lino – quiet environment.	Nothing stated.
7	✓	✓	AO	40 – 49	✓	✓	✓	No difficulty manipulating UI or weight estimation process. Systematic testing.	Light lino – quiet environment.	Nothing stated.
8	✓	✓	AO	30 – 39	✓	✓	✓	No difficulty, found bugs (crash on swipe), tried to swipe instead of click button which this was not a part of instructions.	Light lino – quiet environment.	"Why can't I swipe?", "This would be easier on a dark background with yellow square".

9	✓	✓	AO	20 – 29	✓	✓	✓	No difficulty manipulating UI or weight estimation process	Multi-coloured carpet, noisy environment.	“carpet pattern makes focus difficult”.
10	✓	✓	AO	40 – 49	✓	✗	✗	Found AR difficult, trying not to move/tilt phone. Difficulty focusing on the screen, wears reading glasses. Wanted to stay still not move around.	Multi-coloured carpet, noisy environment.	No comments throughout but was easily distracted by environment.
11	✓	✓	AO	40 – 49	✓	✓	✗	Difficulty with planar cross for aim. Thought, he needed to click in the square despite instructions that he could click anywhere on the screen. Suggested grid could fill in the person automatically/more intuitive.	Dark carpeted surface.	“most apps have the cross stationary and you don’t move the phone”, Concerned “the public may wonder why a photograph is being taken”.
12	✓	✓	RN	50 – 59	✓	✓	✗	No difficulty manipulating application, measurement accurate.	Dark carpeted surface, quiet but cluttered environment.	No problem seeing yellow square and cross but commented “it may be hard on a light surface”.
13	✓	✓	RN, AO	30 – 39	✓	✓	✓	No difficulty manipulating UI or weight estimation process	Solid, dark carpet.	No comments made throughout.
14	✓	✓	RN, AO	40 – 49	✓	✓	✓	No difficulty manipulating UI or weight estimation process. Interestingly quoted formula for weight estimation from Ambulance procedures incorrectly.	Light multi-coloured floor, busy environment.	“I have to use ambulance procedures which means I didn’t need anything else”.
15	✓	✓	D	30 – 39	✓	✓	✓	No difficulty manipulating UI or weight estimation process	Black carpeted floor, busy environment.	“useful app”, “Good idea”

RN = Nurse, AO = Ambulance, D = Doctor

10.6 Appendix F – Code

10.6.1 Main.Storyboard



10.6.2 AppDelegate.swift

```
// AppDelegate.swift
// WEWW Tabbed
// Created by Sally Britnell on 25/08/17.
// Copyright © 2017 Sally Britnell. All rights reserved.

import UIKit
import SceneKit
import ARKit

@UIApplicationMain class AppDelegate: UIResponder, UIApplicationDelegate {
  var window: UIWindow?
  func applicationDidFinishLaunching(_ application: UIApplication) { }
  func applicationWillResignActive(_ application: UIApplication) { }
  func applicationDidEnterBackground(_ application: UIApplication) { }
  func applicationWillEnterForeground(_ application: UIApplication) { }
  func applicationDidBecomeActive(_ application: UIApplication) { }
  func applicationWillTerminate(_ application: UIApplication) { }
}
```

10.6.3 Variables.swift

```
// variables.swift
// WEWW Tabbed
// Created by Sally Britnell on 27/08/17.
// Copyright © 2017 Sally Britnell. All rights reserved.

import Foundation

// This class stores static variables used across the WEWW application
class staticVariables {
  static var testWeight = -1.0
  static var testHeight = -1.0
  static var testing = false
  static var modelLabel = "Height"
  static var ethnicityInt = -1
  static var genderInt = -1
  static var ageInt = -1
  static var knowChildsAge = 0
  static var BSA = -1.000
  static var BMI = Double(-1)
  static var lengthInM = Double(0.0)
  static var weightInKG = Double(-1)
  static var heightInCM = Double(0.0)
  static var startMotion = true
  static var startPitch = 0
  static var startYaw = 0
  static var startRoll = 0
  static var endPitch = 0
  static var endYaw = 0
  static var endRoll = 0
  static var lightIntensity = 0
  static var ethnicityArr = ["Maori","Pacific","Asian","Other","Unknown"]
  static var genderArr = ["Male","Female","Unknown"]
  static var startCoordX = 0.0
  static var startCoordY = 0.0
  static var startCoordZ = 0.0
  static var endCoordX = 0.0
  static var endCoordY = 0.0
  static var endCoordZ = 0.0
  static var apls = 0
}
```

10.6.4 SettingsViewController.swift

```
// SettingsViewController.swift
// WEWW Tabbed
// Created by Sally Britnell on 25/08/17.
// Copyright © 2017 Sally Britnell. All rights reserved.

import UIKit
```

```
import ARKit

class SettingsViewController: UIViewController, UITabBarControllerDelegate ,
UITextFieldDelegate {

  @IBOutlet weak var ageText: UITextField!
  @IBOutlet weak var ethnicityLabel: UILabel!
  @IBOutlet weak var genderLabel: UILabel!
  @IBOutlet weak var measureChildButton: UIButton!
  @IBOutlet weak var maleButton: UIButton!
  @IBOutlet weak var femaleButton: UIButton!
  @IBOutlet weak var unknownGenderButton: UIButton!
  @IBOutlet weak var maoriButton: UIButton!
  @IBOutlet weak var pacificButton: UIButton!
  @IBOutlet weak var asianButton: UIButton!
  @IBOutlet weak var otherButton: UIButton!
  @IBOutlet weak var unknownEthnicity: UIButton!
  var firstRun = true

  // setup the overrides for this view controller
  override func viewDidLoad() {
    super.viewDidLoad()
    ageText.delegate = self
  }
  override func viewDidAppear(_ animated: Bool) {
    super.viewDidAppear(animated)
  }
  override func viewDidDisappear(_ animated: Bool) {
    let get = getWeight()
    staticVariables.weightInKG = get.getWeightInKG()
    super.viewDidDisappear(animated)
  }

  // go to AR tab to measure
  @IBAction func measureChild(_ sender: UIButton) {
    tabBarController?.selectedIndex = 1
  }

  // Enter / return submits text field and releases
  func textFieldShouldReturn(_ textField: UITextField) -> Bool
  {
    textField.resignFirstResponder()
    return true;
  }

  // set the highlight for the button pressed
  func setHighlight(sender: UIButton) {
    if sender.isSelected {
      sender.setTitleColor(UIColor.white, for: UIControl.State.selected)
      sender.backgroundColor = UIColor.blue
    }
    else {
      sender.setTitleColor(UIColor.blue, for: UIControl.State.selected)
      sender.backgroundColor = UIColor.white
    }
  }

  // Set Gender and call update data function to update
  // master variables
  @IBAction func maleGenderAction(_ sender: UIButton) {
    staticVariables.genderInt = 0
    unHighlightGender()
    maleButton.isSelected = true
    setHighlight(sender: sender)
  }
  @IBAction func femaleGenderAction(_ sender: UIButton) {
    staticVariables.genderInt = 1
    unHighlightGender()
    femaleButton.isSelected = true
    setHighlight(sender: sender)
```

```
}
@IBAction func unknownGenderAction(_ sender: UIButton) {
  staticVariables.genderInt = -1
  unHighlightGender()
  unknownGenderButton.isSelected = true
  setHighlight(sender: sender)
}

// set the ethnicity buttons
@IBAction func maoriEthnicityAction(_ sender: UIButton) {
  staticVariables.ethnicityInt = 0
  unHighlightEthnicity()
  sender.isSelected = true
  setHighlight(sender: sender)
}
@IBAction func pacificEthnicityAction(_ sender: UIButton) {
  staticVariables.ethnicityInt = 1
  unHighlightEthnicity()
  sender.isSelected = true
  setHighlight(sender: sender)
}
@IBAction func asianEthnicityAction(_ sender: UIButton) {
  staticVariables.ethnicityInt = 2
  unHighlightEthnicity()
  sender.isSelected = true
  setHighlight(sender: sender)
}
@IBAction func otherEthnicityAction(_ sender: UIButton) {
  staticVariables.ethnicityInt = 3
  unHighlightEthnicity()
  sender.isSelected = true
  setHighlight(sender: sender)
}
  @IBAction func unknownEthnicityAction(_ sender: UIButton) {
  staticVariables.ethnicityInt = -1
  unHighlightEthnicity()
  sender.isSelected = true
  setHighlight(sender: sender)
}

// get the age and change all labels associated with this
@IBAction func setAge(sender: UITextField) -> Void {
  let ageTextField = sender.text
  staticVariables.ageInt = Int(ageTextField!)!
  if staticVariables.ageInt > 0 && staticVariables.ageInt < 15 {
    ageText.text = ageTextField!+" years"
    staticVariables.apls = (staticVariables.ageInt+4)*2
  }
  else {
    staticVariables.ageInt = -1
  }
  if self.view.endEditing(true) {
    return
  }
}

// unhighlight other buttons if a new one is pressed
func unHighlightEthnicity() {
  maoriButton.isSelected = false
  setHighlight(sender: maoriButton)
  pacificButton.isSelected = false
  setHighlight(sender: pacificButton)
  asianButton.isSelected = false
  setHighlight(sender: asianButton)
  otherButton.isSelected = false
  setHighlight(sender: otherButton)
  unknownEthnicity.isSelected = false
  setHighlight(sender: unknownEthnicity)
}
func unHighlightGender() {
```

```
    maleButton.isSelected = false
    setHighlight(sender: maleButton)
    femaleButton.isSelected = false
    setHighlight(sender: femaleButton)
    unknownGenderButton.isSelected = false
    setHighlight(sender: unknownGenderButton)
  }

  // Dispose of any resources that can be recreated.
  override func didReceiveMemoryWarning() {
    super.didReceiveMemoryWarning()
  }
}
```

10.6.5 MeasureARViewController.swift

```
// MeasureARViewController.swift
// WEWW Tabbed
// Created by Sally Britnell on 25/08/17.
// Copyright © 2017 Sally Britnell. All rights reserved.

import UIKit
import SceneKit
import ARKit
import CoreML
import CoreMotion

class MeasureARViewController: UIViewController, ARSCNViewDelegate,
UITabBarControllerDelegate {

  // Set up the variables and scene viewer
  @IBOutlet weak var sceneView: ARSCNView!
  var distanceLabel = UILabel()
  var gender: Int = 0
  var ethnicity: Int = 0
  var age: Int = 0
  var trackingStateLabel = UILabel()
  var startNode: SCNNode!
  var endNode: SCNNode!
  var sphereNode: SCNNode!
  var sphereNodePosition: SCNVector3!
  var width = UIScreen.main.bounds.width
  var height = UIScreen.main.bounds.height
  var dragOnInfinitePlanesEnabled = false
  var color = UIColor(red: 100.0/255.0, green: 130.0/255.0, blue: 230.0/255.0,
alpha: 1.0)
  var focusSquare = FocusSquare()

  // lets the current view controller know that you are going to change to
another view controller
  override func prepare(for segue: UIStoryboardSegue, sender: Any?) {
    let get = getWeight()
    staticVariables.weightInKG = get.getWeightInKG()
    let resultsController = segue.destination as! resultsTableController
    resultsController.setResults()
  }

  // Let the view controller know that it will be added to the view controller
hierarchy
  override func viewWillAppear(_ animated: Bool) {
    super.viewWillAppear(animated)

    // Create a session configuration that uses the back-facing camera to
allow position tracking and detection
    let configuration = ARWorldTrackingConfiguration()

    // let the phone automatically detect horizontal surfaces only
    configuration.planeDetection =
ARWorldTrackingConfiguration.PlaneDetection.horizontal

    // Run the view's session start using AR with the world tracking enabled
```

```
    sceneView.session.run(configuration)
  }

  // Pause the view's session and make sure weight static variable is updated
first
  override func viewWillDisappear(_ animated: Bool) {
    super.viewWillDisappear(animated)
    let get = getWeight()
    staticVariables.weightInKG = get.getWeightInKG()
    sceneView.session.pause()
  }

  override func viewDidLoad() {
    super.viewDidLoad()
    // Set the view's delegate
    sceneView.delegate = self
    // Show statistics such as fps and timing information
    sceneView.showsStatistics = false
    // Get ready to accept input in the form of screen taps
    let tapGestureRecognizer = UITapGestureRecognizer(target: self, action:
#selector(MeasureARViewController.handleTapGesture))
    view.addGestureRecognizer(tapGestureRecognizer)
    // setup other items
    setupFocusSquare()
    updateFocusSquare()
    setUpLabels()
  }

  func setUpLabels() {
    distanceLabel.text = "point camera at surface next to child until solid
outline around square"
    distanceLabel.textColor = .yellow
    trackingStateLabel.text = "then tap screen when solid outline of square is
at top of child's head"
    distanceLabel.frame = CGRect(x: 10, y: 55, width: 300, height: 50)
    trackingStateLabel.frame = CGRect(x: 10, y: 105, width: 300, height: 50)
    trackingStateLabel.numberOfLines = 2
    distanceLabel.numberOfLines = 2
    view.addSubview(distanceLabel)
    view.addSubview(trackingStateLabel)
  }

  override func didReceiveMemoryWarning() {
    super.didReceiveMemoryWarning()
  }

  // If the measure is outside the parameters return message
  func outsideParameters () -> String {
    return "Please measure agian"
  }

  // manage user interaction
  @objc func handleTapGesture(sender: UITapGestureRecognizer) {
    if sender.state != .ended {
      return
    }
    guard sceneView.session.currentFrame != nil else
    {
      return
    }

    setMotionData()
    // reset to measure again
    if let endNode = endNode {

      // remove the node from its parent nodes array restart the measure
      startNode?.removeFromParentNode()
      endNode.removeFromParentNode()
      self.startNode = nil
      self.endNode = nil
```

```
      distanceLabel.text = ""
      trackingStateLabel.text = ""
      distanceLabel.text = "Point the camera at the surface the child is on"
      trackingStateLabel.text = "... then tap screen when solid outline square
is at top of child's head"
      return
    }

    // hit test looks for points on a real-world plane that has already been
detected
    let planeHitTestResults = sceneView.hitTest(view.center,
types: .existingPlaneUsingExtent)

    // if the plane has objects create a sphere node and place this in the
last position of the focus square
    if planeHitTestResults.first != nil {

      // if the start node is already set this must be the end node
      if let startNode = startNode {

        endNode = setUpSphere()
        let vector = startNode.position - endNode.position
        let formatter = NumberFormatter()
        formatter.numberStyle = .decimal
        formatter.roundingMode = .ceiling
        formatter.maximumFractionDigits = 2

        // get the distance between the nodes in m and cm and put in static
variables
        staticVariables.lengthInM = Double(truncating: NSNumber(value:
vector.length()))
        staticVariables.heightInCM = staticVariables.lengthInM*100
        let TAC = 90
        let TAA = abs(staticVariables.startPitch)
        let TAB = 180-TAC-TAA
        let TAb = abs(startNode.position.y)*100
        let TAa = abs((Double(TAb)*sin(Double(TAA))/sin(Double(TAB))))
        let TAc = abs((Double(TAb)*sin(Double(TAC))/sin(Double(TAB))))
        print("TAA = "+String(TAA))
        print("TAB = "+String(TAB))
        print("TAC = "+String(TAC))
        print("TAa = "+String(TAa))
        print("TAb = "+String(TAb))
        print("TAc = "+String(TAc))

        let TBA = abs(staticVariables.endPitch)
        let TBC = 180-TAB
        let TBB = 180-TBA-TBC

        let TBb = TAc
        let TBa = abs(Double(TBb)*sin(Double(TBA))/sin(Double(TBB)))
        let TBc = abs(Double(TBb)*sin(Double(TBC))/sin(Double(TBB)))

        print("TBA = "+String(TBA))
        print("TBB = "+String(TBB))
        print("TBC = "+String(TBC))
        print("TBa = "+String(TBa))
        print("TBb = "+String(TBb))
        print("TBc = "+String(TBc))

        print("length = "+String(TBc)+" cm")

        print("Start distance to Plane =
"+String(startNode.position.y)+"Distance to x =
"+String(startNode.position.x)+"Z coordinate = "+String(startNode.position.z))

        trackingStateLabel.text = "Tap to measure again"
        // change 1 to desired number of seconds
        let when = DispatchTime.now() + 1
        // Go to the results screen
```

```
        DispatchQueue.main.asyncAfter(deadline: when) {
          self.setMotionData()
          self.tabBarController?.selectedIndex = 2
        }
      }
      else {
        startNode = setUpSphere()
        distanceLabel.text = "You have the first point"
        trackingStateLabel.text = "tap screen when the square has a solid and
the cross is at the head / feet"

      }
    }
    else {
//      distanceLabel.text = ""
//      trackingStateLabel.text = ""
//       trackingStateLabel.text = "move the phone to make the square solid
then tap"

//      // Create a transform with a translation of 0.1 meters (10 cm) in
front of the camera if none is set
//      var translation = matrix_identity_float4x4
//      translation.columns.3.z = -0.1
//
//      if let startNode = startNode {
//        endNode = setUpSphere()
//        let currentDistance = distance(startNode: startNode, endNode:
sphereNode)
//        staticVariables.lengthInM = Double(currentDistance)
//        staticVariables.heightInCM = staticVariables.lengthInM*100
//        self.setMotionData()
//      }
//      else {
//        startNode = sphereNode
//      }
    }
  }

  // set up sphere
  func setUpSphere() -> (SCNNode) {
    let sphere = SCNSphere(radius: 0.005)
    sphere.firstMaterial?.diffuse.contents = UIColor.red
    sphere.firstMaterial?.lightingModel = .constant
    sphere.firstMaterial?.isDoubleSided = true

    // node is in coordinate space
    let node = SCNNode(geometry: sphere)
    node.position = focusSquare.lastPositionOnPlane!
    sceneView.scene.rootNode.addChildNode(node)
    return node
  }

  // Get data to capture motion
  func setMotionData() {
    let motionManager = CMMotionManager()
    if motionManager.isDeviceMotionAvailable == true {
      let queue = OperationQueue()
      motionManager.startDeviceMotionUpdates(to: queue) { (motion,
deviceError) in
        motionManager.deviceMotionUpdateInterval = 0.1
        let attitude = motionManager.deviceMotion?.attitude
        motionManager.startDeviceMotionUpdates()
        let PI = 3.14159265
        let yaw = (attitude?.yaw)! * 180/PI
        let pitch = (attitude?.pitch)! * 180/PI
        let roll = (attitude?.roll)! * 180/PI
        if staticVariables.startMotion == true {
          staticVariables.startYaw = Int(yaw)
          staticVariables.startRoll = Int(roll)
          staticVariables.startPitch = Int(pitch)
```

```
          staticVariables.startMotion = false
        }
        else {
          staticVariables.endYaw = Int(yaw)
          staticVariables.endRoll = Int(roll)
          staticVariables.endPitch = Int(pitch)
          staticVariables.startMotion = true
        }
      }

    }
    else {
      print("device motion not available")
    }
  }

  func distance(startNode: SCNNode, endNode: SCNNode) -> Double {

    // determine the distance between start and end nodes to measure distance
    let vector = SCNVector3Make(startNode.position.x - endNode.position.x,
startNode.position.y - endNode.position.y, startNode.position.z -
endNode.position.z)

    // Scene units map to meters in ARKit.
    let distanceF = sqrtf(vector.x * vector.x + vector.y * vector.y + vector.z
* vector.z)
    let distanceD = Double(distanceF)
    print("Distance to Floor")
    print(endNode.position.x - startNode.position.x)
    staticVariables.lengthInM = distanceD
    return distanceD
  }

  static func angleBetweenPointsToHorizontalPlane(p1:vector_float3,
p2:vector_float3) -> Float {

    ///Point in 3d space on the same level of p1 but equal to p2
    let p2Hor = vector_float3.init(p2.x, p1.y, p2.z)
    let p1ToP2Norm = normalize(p2 - p1)
    let p1ToP2HorNorm = normalize(p2Hor - p1)
    let dotProduct = dot(p1ToP2Norm, p1ToP2HorNorm)
    let angle = acos(dotProduct)
    return angle
  }

  // ARSCNView Delegate
  func renderer(_ renderer: SCNSceneRenderer, updateAtTime time: TimeInterval)
{
    DispatchQueue.main.async {
      self.updateFocusSquare()
    }
  }

  func session(_ session: ARSession, cameraDidChangeTrackingState camera:
ARCamera) {
    switch camera.trackingState {
    case .notAvailable:
      trackingStateLabel.text = "Error"
      trackingStateLabel.textColor = .red
    case .normal:
      trackingStateLabel.text = "... then tap screen when solid outline square
is at top of child's head"
      trackingStateLabel.textColor = .green
    case .limited(let reason):
      switch reason {
      case .excessiveMotion:
        trackingStateLabel.text = "excessive motion - hold still"
      case .insufficientFeatures:
        trackingStateLabel.text = "insufficient features"
      case .initializing:
```

```
        trackingStateLabel.text = "... loading"
              case .relocalizing: break
      }
      trackingStateLabel.textColor = .yellow
    }
  }

  func setupFocusSquare() {
    focusSquare.isHidden = true
    focusSquare.removeFromParentNode()
    focusSquare = FocusSquare()
    sceneView.scene.rootNode.addChildNode(focusSquare)
  }

  func updateFocusSquare() {
    focusSquare.unhide()

    // start with focus square in the middle of the screen
    let (worldPosition, planeAnchor, _) =
worldPositionFromScreenPosition(view.center, objectPos: focusSquare.position)

    if let worldPosition = worldPosition {
      focusSquare.update(for: worldPosition, planeAnchor: planeAnchor, camera:
sceneView.session.currentFrame?.camera)
    }
  }
}

extension MeasureARViewController {

  func worldPositionFromScreenPosition(_ position: CGPoint,objectPos:
SCNVector3?, infinitePlane: Bool = false) -> (position: SCNVector3?,
planeAnchor: ARPlaneAnchor?, hitAPlane: Bool) {

    // plane distance set the plane hit test results to the position on the
current plane
    let planeHitTestResults = sceneView.hitTest(position,
types: .existingPlaneUsingExtent)

    // if the first result update the plane anchor to match the place on the
screen tapped
    if let result = planeHitTestResults.first {

      // set hit test position to be the plane anchor or center of the focus
squre
      let planeHitTestPosition =
SCNVector3.positionFromTransform(result.worldTransform)
      let planeAnchor = result.anchor

      // Return immediately
      return (planeHitTestPosition, planeAnchor as? ARPlaneAnchor, true)
    }

    // Collect information about the environment by hit testing against the
feature point cloud, but do not return the
    // result yet.
    var featureHitTestPosition: SCNVector3?
    var highQualityFeatureHitTestResult = false
    let highQualityfeatureHitTestResults =
sceneView.hitTestWithFeatures(position, coneOpeningAngleInDegrees: 18,
minDistance: 0.2, maxDistance: 2.0)
    if !highQualityfeatureHitTestResults.isEmpty {
      let result = highQualityfeatureHitTestResults[0]
      featureHitTestPosition = result.position
      highQualityFeatureHitTestResult = true
    }

    // If desired or necessary (no good feature hit test result): Hit test
against an infinite, horizontal plane (ignoring
    // the real-world).
```

```
    if (infinitePlane && dragOnInfinitePlanesEnabled)
|| !highQualityFeatureHitTestResult {
      let pointOnPlane = objectPos ?? SCNVector3Zero
      let pointOnInfinitePlane =
sceneView.hitTestWithInfiniteHorizontalPlane(position, pointOnPlane)
      if pointOnInfinitePlane != nil {
        return (pointOnInfinitePlane, nil, true)
      }
    }

    // If available, return the result of the hit test against high quality
features if the hit tests against infinite
    // planes were skipped or no infinite plane was hit.
    if highQualityFeatureHitTestResult {
      return (featureHitTestPosition, nil, false)
    }

    // As a last resort, perform a second, unfiltered hit test against
features. If there are no features in the scene,
    // the result returned here will be nil.
    let unfilteredFeatureHitTestResults =
sceneView.hitTestWithFeatures(position, coneOpeningAngleInDegrees: 180)
    if !unfilteredFeatureHitTestResults.isEmpty {
      let result = unfilteredFeatureHitTestResults[0]
      return (result.position, nil, false)
    }
    return (nil, nil, false)
  }
}
```

10.6.6 getWeight.swift

```
// getWeight.swift
// WEWW Tabbed
// Created by Sally Britnell on 14/02/18.
// Copyright © 2018 Sally Britnell. All rights reserved.

import Foundation
import UIKit

var weight = 0.0

// lets the current view controller know that you are going to change to
another view controller
func prepare(for segue: UIStoryboardSegue, sender: Any?) {
  let homeController = segue.destination as! resultsTableController
  homeController.setResults()
}
```

10.6.7 setWeight.swift

```
// getWeight.swift
// WEWW Tabbed
// Created by Sally Britnell on 14/02/18.
// Copyright © 2018 Sally Britnell. All rights reserved.

import Foundation
import UIKit

var weight = 0.0

// prepare for a change to the results screen
func prepare(for segue: UIStoryboardSegue, sender: Any?) {
  let homeController = segue.destination as! resultsTableController
  homeController.setResults()
}

class getWeight {

  // predict the weight and return this as a double
  func getWeightInKG() -> Double {
    var returnValue:Int
```

```
    let predictedWeight = getModel(age: Double(staticVariables.ageInt),
gender: Double(staticVariables.genderInt), ethnicity:
Double(staticVariables.ethnicityInt+1), height: staticVariables.heightInCM)
    staticVariables.weightInKG = predictedWeight
    staticVariables.BMI = getBMI(heightInCM: staticVariables.heightInCM,
weight: predictedWeight)
    staticVariables.BSA = getBSA(weight: predictedWeight)
    if staticVariables.heightInCM > 195 || staticVariables.heightInCM < 35 ||
staticVariables.weightInKG < 0 {
      returnValue = Int(-1)
    }
    else {
      returnValue = Int(predictedWeight)
    }
    return Double(returnValue)
  }

  // calculate the body surface area and return this as a double
  func getBSA(weight:Double) -> Double {
    let BSA = Double(((weight*weight)/3600).squareRoot())
    if BSA.isNaN || staticVariables.BMI == -1 {
      return -1
    }
    else {
      return BSA
    }
  }

  // calculate the BMI and return this as a double
  func getBMI(heightInCM:Double, weight:Double) -> Double {
    let heightM = heightInCM/100
    let heightSquared = heightM*heightM
    let BMI = Double(weight/heightSquared)
    if BMI.isNaN {
      return -1
    }
    else {
      return BMI
    }
  }

  // select the regression model to use based on the parameters the user
provided and use this to predict the weight of the child
  func getModel(age:Double, gender:Double, ethnicity:Double, height:Double) ->
Double {

    if gender > -1 && ethnicity > 0 && age > -1 { // AEGH //
[gende,ethnicity,age]
      let model = AEGH_linear_model()
      staticVariables.modelLabel = "Age, Ethnicity, Gender, Height"
      guard let output = try? model.prediction(age: age, ethnicity: ethnicity,
gender: gender, height: height) else { fatalError("Unexpected runtime
error.") }
      return output.prediction
    }
    if gender == -1 && ethnicity > 0 && age > -1 { // AEH
[gender,ethnicity,age]
      let model = AEH_linear_model()
            staticVariables.modelLabel = "Age, Ethnicity, Height"
      guard let output = try? model.prediction(age: age, ethnicity: ethnicity,
height: height) else { fatalError("Unexpected runtime error.") }
      return output.prediction
    }
    if gender > -1 && ethnicity < 1 && age > -1 { // AGH [age,gender,height]
      let model = AGH_linear_model()
            staticVariables.modelLabel = "Age, Gender, Height"
      guard let output = try? model.prediction(age: age, gender: gender,
height: height) else { fatalError("Unexpected runtime error.") }
      return output.prediction
    }
```

```
    if gender == -1, ethnicity < 1, age != -1 { // AH [gender,ethnicity,age]
      let model = AH_linear_model()
            staticVariables.modelLabel = "Age, Height"
      guard let output = try? model.prediction(age: age, height: height) else
{ fatalError("Unexpected runtime error.") }
      return output.prediction
    }
    if gender > -1 && ethnicity > 0 && age == -1 { // EGH
[gender,ethnicity,age]
      let model = EGH_linear_model()
            staticVariables.modelLabel = "Ethnicity, Gender, Height"
      guard let output = try? model.prediction(ethnicity: ethnicity, gender:
gender, height: height) else { fatalError("Unexpected runtime error.") }
      return output.prediction
    }
    if gender > -1 && ethnicity < 1 && age == -1 { // GH
[gender,ethnicity,age]
      let model = GH_linear_model()
            staticVariables.modelLabel = "Gender, Height"
      guard let output = try? model.prediction(gender: gender, height: height)
else { fatalError("Unexpected runtime error.") }
      return output.prediction
    }
    if gender == -1 && ethnicity > 0 && age == -1 { // EH
[gender,ethnicity,age]
      let model = EH_linear_model()
      staticVariables.modelLabel = "Ethnicity, Height"
      guard let output = try? model.prediction(ethnicity: ethnicity, height:
height) else { fatalError("Unexpected runtime error.") }
      return output.prediction
    }
    else {
      let model = H_linear_model()
      staticVariables.modelLabel = "Height"
      guard let output = try? model.prediction(height: height)
        else { fatalError("Unexpected runtime error.")
      }
      return output.prediction
    }
  }
}
```

10.6.8 ResultsViewController.swift

```
// ResultsViewController.swift
// WEWW Tabbed
//
// Created by Sally Britnell on 12/02/18.
// Copyright © 2018 Sally Britnell. All rights reserved.

import Foundation
import UIKit

class resultsTableController: UIViewController, UITabBarControllerDelegate {

  @IBOutlet var demographics: UIView!
  @IBOutlet weak var genderResults: UILabel!
  @IBOutlet weak var genderLabel: UILabel!
  @IBOutlet weak var ageLabel: UILabel!
  @IBOutlet weak var ageResults: UILabel!
  @IBOutlet weak var ethnicityLabel: UILabel!
  @IBOutlet weak var ethnicityResults: UILabel!
  @IBOutlet weak var testValues: UILabel!
  @IBOutlet weak var APLSLabel: UILabel!
  @IBOutlet weak var aplsResults: UILabel!
  @IBOutlet weak var actualValues: UILabel!
  @IBOutlet weak var heightLabel: UILabel!
  @IBOutlet weak var heightResults: UILabel!
  @IBOutlet weak var weightLabel: UILabel!
  @IBOutlet weak var weightResults: UILabel!
  @IBOutlet weak var modelLabel: UILabel!
```

```
  @IBOutlet weak var modelResults: UILabel!
  @IBOutlet weak var calculatedValues: UILabel!
  @IBOutlet weak var BMILabel: UILabel!
  @IBOutlet weak var BMIResults: UILabel!
  @IBOutlet weak var BSALabel: UILabel!
  @IBOutlet weak var BSAResults: UILabel!

 // override extensions for this class
  internal override func viewDidLoad() {
    super.viewDidLoad()
    setResults()
  }
  internal override func viewWillAppear(_ animated: Bool) {
    super.viewWillAppear(animated)
    setResults()
  }
  internal override func viewDidDisappear(_ animated: Bool) {
    super.viewDidDisappear(animated)
  }

  // populate the results labels with text strings
  func setResults() {
    let get = getWeight()
    staticVariables.weightInKG = get.getWeightInKG()
    ageResults.text = getAge()
    aplsResults.text = getAPLS()
    genderResults.text = getGender()
    ethnicityResults.text = getEthnicity()
    heightResults.text = getHeight()
    weightResults.text = returnWeight()
    modelResults.text = staticVariables.modelLabel
    BMIResults.text = getBMI()
    BSAResults.text = getBSA()
    tabBarController?.selectedIndex = 2
  }

  func getBMI() -> String {
    if staticVariables.BMI.isNaN || staticVariables.BMI < 0 {
      return "Unknown"
    }
    else {
      return String(format: "%.1f", Double(staticVariables.BMI))
    }
  }
  func getBSA() -> String {
    if staticVariables.BSA < 0 || staticVariables.BSA.isNaN || getBMI() ==
"Unknown"{
      return "Unknown"
    }
    else {
      return String(format: "%.3f", staticVariables.BSA)+"m2"
    }
  }
  func getAge() -> String {
    if staticVariables.ageInt < 1 || staticVariables.ageInt > 14 {
      return "Unknown"
    }
    else {
      return String(staticVariables.ageInt)+" years"
    }
  }
  func getHeight() -> String {
    return String(format: "%.1f", staticVariables.heightInCM)+" cm"
  }
  func returnWeight() -> String {
    if staticVariables.weightInKG < 3.5 {
      return "Outside Param."
    }
    else {
      let weight = getWeight()
```

```
      return String(format: "%.1f",
              Double(weight.getWeightInKG())+" kg"
    }
  }
  func getGender() -> String {
    if staticVariables.genderInt < 0 {
      return "Unknown"
    }
    else {
      return staticVariables.genderArr[staticVariables.genderInt]
    }
  }
  func getEthnicity() -> String {
    if staticVariables.ethnicityInt < 0 {
      return "Unknown"
    }
    else {
      return staticVariables.ethnicityArr[staticVariables.ethnicityInt]
    }
  }
  func getAPLS() -> String {
    if staticVariables.ageInt < 0 {
      return "Unknown"
    }
    else {
      staticVariables.apls = (staticVariables.ageInt+4)*2
      return String(staticVariables.apls)+" kg"
    }
  }
}
```

10.6.9 resultsModel.swift

```
// resultsModel.swift
// WEWW Tabbed
//
// Created by Sally Britnell on 13/02/18.
// Copyright © 2018 Sally Britnell. All rights reserved.

import Foundation
import UIKit

// this class houses functions that return the paramaters as
// strings for display in the results
class resultsModel: NSObject {

  func getBMI() -> String {
    if staticVariables.BMI.isNaN || staticVariables.BMI < 0 {
      return "Unknown"
    }
    else {
      return String(format: "%.1f", Double(staticVariables.BMI))
    }
  }

  func getBSA() -> String {
    if staticVariables.BSA < 0 || staticVariables.BSA.isNaN || getBMI() ==
"Unknown"{
      return "Unknown"
    }
    else {
      return String(format: "%.3f", staticVariables.BSA)+"m2"
    }
  }

  func getAge() -> String {
    if staticVariables.ageInt < 1 || staticVariables.ageInt > 14 {
      return "Unknown"
    }
    else {
      return String(staticVariables.ageInt)+" years"
```

```
    }
  }

  func getHeight() -> String {
    return String(format: "%.1f", staticVariables.heightInCM)+" cm"
  }

  func returnWeight() -> String {
    if staticVariables.weightInKG < 3.5 {
      return "Outside Param."
    }
    else {
      let weight = getWeight()
      return String(format: "%.1f",
              Double(weight.getWeightInKG()))+" kg"
    }
  }

  func getGender() -> String {
    if staticVariables.genderInt < 0 {
      return "Unknown"
    }
    else {
      return staticVariables.genderArr[staticVariables.genderInt]
    }
  }

  func getEthnicity() -> String {
    if staticVariables.ethnicityInt < 0 {
      return "Unknown"
    }
    else {
      return staticVariables.ethnicityArr[staticVariables.ethnicityInt]
    }
  }

  func getAPLS() -> String {
    if staticVariables.ageInt < 0 {
      return "Unknown"
    }
    else {
      staticVariables.apls = (staticVariables.ageInt+4)*2
      return String(staticVariables.apls)+" kg"
    }
  }

  func getTestHeight() -> String {
    if staticVariables.testHeight < 0 {
      return "Unknown"
    }
    else {
      return String(staticVariables.testHeight)+" cm"
    }
  }
}
```

10.6.10FocusSquare.swift

```
// This code was adapted from ARKit-Example-by-Apple
// (https://github.com/gao0122/ARKit-Example-by-Apple )
// Adapted by Sally Britnell on 25/08/17.

import Foundation
import ARKit

// This class creates and controls the focus square
class FocusSquare: SCNNode {

  // Original size of the focus square in m.
  private let focusSquareSize: Float = 0.17
```

```
  // Thickness of the focus square lines in m.
  private let focusSquareThickness: Float = 0.025

  // Scale factor for the focus square when it is closed,
  // w.r.t. the original size.
  private let scaleForClosedSquare: Float = 0.97

  // Side length of the focus square segments when it is open
  // (w.r.t. to a 1x1 square).
  private let sideLengthForOpenSquareSegments: CGFloat = 0.2

  // Duration of the open/close animation
  private let animationDuration = 0.7

  // Color of the focus square
  private let focusSquareColor = #colorLiteral(red: 1, green: 0.8288275599,
blue: 0, alpha: 1) // base yellow
  private let focusSquareColorLight = #colorLiteral(red: 1, green:
0.9312674403, blue: 0.4846551418, alpha: 1) // light yellow

  var lastPositionOnPlane: SCNVector3?
  var lastPosition: SCNVector3?

  override init() {
    super.init()
    self.opacity = 0.0
    self.addChildNode(focusSquareNode())
    open()
    lastPositionOnPlane = nil
    lastPosition = nil
    recentFocusSquarePositions = []
    anchorsOfVisitedPlanes = []
  }

  required init?(coder aDecoder: NSCoder) {
    fatalError("init(coder:) has not been implemented")
  }

  func update(for position: SCNVector3, planeAnchor: ARPlaneAnchor?, camera:
ARCamera?) {
    lastPosition = position
    // close the square if the planeanchor has not been visited update the
position and insert it into visited planes otherwise keep the square open
    if let anchor = planeAnchor {
      close(flash: !anchorsOfVisitedPlanes.contains(anchor))
      lastPositionOnPlane = position
      anchorsOfVisitedPlanes.insert(anchor)
    } else {
      open()
    }
    updateTransform(for: position, camera: camera)
  }

  func unhide() {
    if self.opacity == 0.0 {
      self.runAction(SCNAction.fadeIn(duration: 0.5))
    }
  }

  private var isOpen = false
  // use average of recent positions to avoid jitter
  private var recentFocusSquarePositions = [SCNVector3]()

  private var anchorsOfVisitedPlanes: Set<ARAnchor> = []

  private func updateTransform(for position: SCNVector3, camera: ARCamera?) {

    // add current position to list of recent positions
    recentFocusSquarePositions.append(position)
```

```
    // remove anything older than the last 8 positions
    recentFocusSquarePositions.keepLast(8)

    // move to average of recent positions to avoid jitter
    if let average = recentFocusSquarePositions.average {
      self.position = average
      self.setUniformScale(scaleBasedOnDistance(camera: camera))
    }

    // Correct y rotation of camera square pitch, yaw, roll
    if let camera = camera {
      let tilt = abs(camera.eulerAngles.x)
      let threshold1: Float = Float.pi / 2 * 0.65
      let threshold2: Float = Float.pi / 2 * 0.75
      let yaw = atan2f(camera.transform.columns.0.x,
camera.transform.columns.1.x)
      var angle: Float = 0

      switch tilt {
      case 0..<threshold1:
        angle = camera.eulerAngles.y
      case threshold1..<threshold2:
        let relativeInRange = abs((tilt - threshold1) / (threshold2 -
threshold1))
        let normalizedY = normalize(camera.eulerAngles.y,
forMinimalRotationTo: yaw)
        angle = normalizedY * (1 - relativeInRange) + yaw * relativeInRange
      default:
        angle = yaw
      }
      self.rotation = SCNVector4Make(0, 1, 0, angle)
    }
  }

  private func normalize(_ angle: Float, forMinimalRotationTo ref: Float) ->
Float {
    // Normalize angle in steps of 90 degrees such that the rotation to the
other angle is minimal
    var normalized = angle
    while abs(normalized - ref) > Float.pi / 4 {
      if angle > ref {
        normalized -= Float.pi / 2
      } else {
        normalized += Float.pi / 2
      }
    }
    return normalized
  }

  private func scaleBasedOnDistance(camera: ARCamera?) -> Float {
    if let camera = camera {
      let distanceFromCamera = (self.worldPosition -
SCNVector3.positionFromTransform(camera.transform)).length()
      // This function reduces size changes of the focus
      // square based on the distance by scaling it up if
      // it far away, and down if it is very close.
      // The values are adjusted such that scale will be 1
      // in 0.7 m distance (estimated distance when
      // looking at a table), and 1.2 in 1.5 m distance
      // (estimated distance when looking at the floor).
      let newScale = distanceFromCamera < 0.7 ? (distanceFromCamera / 0.7) :
(0.25 * distanceFromCamera + 0.825)

      return newScale
    }
    return 1.0
  }

  private func pulseAction() -> SCNAction {
    let pulseOutAction = SCNAction.fadeOpacity(to: 0.4, duration: 0.5)
```

```
    let pulseInAction = SCNAction.fadeOpacity(to: 1.0, duration: 0.5)
    pulseOutAction.timingMode = .easeInEaseOut
    pulseInAction.timingMode = .easeInEaseOut

    return SCNAction.repeatForever(SCNAction.sequence([pulseOutAction,
pulseInAction]))
  }

  private func stopPulsing(for node: SCNNode?) {
    node?.removeAction(forKey: "pulse")
    node?.opacity = 1.0
  }

  private var isAnimating: Bool = false

  private func open() {
    if isOpen || isAnimating {
      return
    }

    // Open animation
    SCNTransaction.begin()
    SCNTransaction.animationTimingFunction = CAMediaTimingFunction(name:
CAMediaTimingFunctionName.easeOut)
    SCNTransaction.animationDuration = animationDuration / 4
    entireSquare?.opacity = 1.0
    self.segments?[0].open(direction: .left, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[1].open(direction: .right, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[2].open(direction: .up, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[3].open(direction: .up, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[4].open(direction: .down, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[5].open(direction: .down, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[6].open(direction: .left, newLength:
sideLengthForOpenSquareSegments)
    self.segments?[7].open(direction: .right, newLength:
sideLengthForOpenSquareSegments)
    SCNTransaction.completionBlock =
{ self.entireSquare?.runAction(self.pulseAction(), forKey: "pulse") }
    SCNTransaction.commit()

    // Scale/bounce animation
    SCNTransaction.begin()
    SCNTransaction.animationTimingFunction = CAMediaTimingFunction(name:
CAMediaTimingFunctionName.easeOut)
    SCNTransaction.animationDuration = animationDuration / 4
    entireSquare?.setUniformScale(focusSquareSize)
    SCNTransaction.commit()

    isOpen = true
  }

  private func close(flash: Bool = false) {
    if !isOpen || isAnimating {
      return
    }

    isAnimating = true
    stopPulsing(for: entireSquare)

    // Close animation
    SCNTransaction.begin()
    SCNTransaction.animationTimingFunction = CAMediaTimingFunction(name:
CAMediaTimingFunctionName.easeOut)
    SCNTransaction.animationDuration = self.animationDuration / 2
```

```
    entireSquare?.opacity = 0.99
    SCNTransaction.completionBlock = {
      SCNTransaction.begin()
      SCNTransaction.animationTimingFunction = CAMediaTimingFunction(name:
CAMediaTimingFunctionName.easeOut)
      SCNTransaction.animationDuration = self.animationDuration / 4
      self.segments?[0].close(direction: .right)
      self.segments?[1].close(direction: .left)
      self.segments?[2].close(direction: .down)
      self.segments?[3].close(direction: .down)
      self.segments?[4].close(direction: .up)
      self.segments?[5].close(direction: .up)
      self.segments?[6].close(direction: .right)
      self.segments?[7].close(direction: .left)
      SCNTransaction.completionBlock = { self.isAnimating = false }
      SCNTransaction.commit()
    }
    SCNTransaction.commit()

    // Scale/bounce animation
    entireSquare?.addAnimation(scaleAnimation(for: "transform.scale.x"),
forKey: "transform.scale.x")
    entireSquare?.addAnimation(scaleAnimation(for: "transform.scale.y"),
forKey: "transform.scale.y")
    entireSquare?.addAnimation(scaleAnimation(for: "transform.scale.z"),
forKey: "transform.scale.z")

    // Flash
    if flash {
      let waitAction = SCNAction.wait(duration: animationDuration * 0.75)
      let fadeInAction = SCNAction.fadeOpacity(to: 0.25, duration:
animationDuration * 0.125)
      let fadeOutAction = SCNAction.fadeOpacity(to: 0.0, duration:
animationDuration * 0.125)
      fillPlane?.runAction(SCNAction.sequence([waitAction, fadeInAction,
fadeOutAction]))

      let flashSquareAction = flashAnimation(duration: animationDuration *
0.25)
      segments?[0].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[1].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[2].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[3].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[4].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[5].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[6].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))
      segments?[7].runAction(SCNAction.sequence([waitAction,
flashSquareAction]))

    }

    isOpen = false
  }

  private func flashAnimation(duration: TimeInterval) -> SCNAction {
    let action = SCNAction.customAction(duration: duration) { (node,
elapsedTime) -> Void in
      // animate color from HSB 48/100/100 to 48/30/100 and back
      let elapsedTimePercentage = elapsedTime / CGFloat(duration)
      let saturation = 2.8 * (elapsedTimePercentage - 0.5) *
(elapsedTimePercentage - 0.5) + 0.3
      if let material = node.geometry?.firstMaterial {
        material.diffuse.contents = UIColor(hue: 0.1333, saturation:
saturation, brightness: 1.0, alpha: 1.0)
```

```
      }
    }
    return action
  }

  private func scaleAnimation(for keyPath: String) -> CAKeyframeAnimation {
    let scaleAnimation = CAKeyframeAnimation(keyPath: keyPath)

    let easeOut = CAMediaTimingFunction(name:
CAMediaTimingFunctionName.easeOut)
    let easeInOut = CAMediaTimingFunction(name:
CAMediaTimingFunctionName.easeInEaseOut)
    let linear = CAMediaTimingFunction(name: CAMediaTimingFunctionName.linear)

    let fs = focusSquareSize
    let ts = focusSquareSize * scaleForClosedSquare
    let values = [fs, fs * 1.15, fs * 1.15, ts * 0.97, ts]
    let keyTimes: [NSNumber] = [0.00, 0.25, 0.50, 0.75, 1.00]
    let timingFunctions = [easeOut, linear, easeOut, easeInOut]

    scaleAnimation.values = values
    scaleAnimation.keyTimes = keyTimes
    scaleAnimation.timingFunctions = timingFunctions
    scaleAnimation.duration = animationDuration

    return scaleAnimation
  }

  private var segments: [FocusSquareSegment]? {
    guard let s1 = childNode(withName: "s1", recursively: true) as?
FocusSquareSegment,
      let s2 = childNode(withName: "s2", recursively: true) as?
FocusSquareSegment,
      let s3 = childNode(withName: "s3", recursively: true) as?
FocusSquareSegment,
      let s4 = childNode(withName: "s4", recursively: true) as?
FocusSquareSegment,
      let s5 = childNode(withName: "s5", recursively: true) as?
FocusSquareSegment,
      let s6 = childNode(withName: "s6", recursively: true) as?
FocusSquareSegment,
      let s7 = childNode(withName: "s7", recursively: true) as?
FocusSquareSegment,
      let s8 = childNode(withName: "s8", recursively: true) as?
FocusSquareSegment
      else {
        return nil
    }
    return [s1, s2, s3, s4, s5, s6, s7, s8]
  }

  private var fillPlane: SCNNode? {
    return childNode(withName: "fillPlane", recursively: true)
  }

  private var entireSquare: SCNNode? {
    return self.childNodes.first
  }

  private func focusSquareNode() -> SCNNode {
    // The focus square consists of eight segments as
    // follows, which can be individually animated.
    //  s1 s2
    //    _  _
    // s3¯|  ¯ | s4

    // s5 |    | s6
    //    -  -
    //  s7 s8
    let sl: Float = 0.5 // segment length
```

```
    let st = focusSquareThickness
    let c: Float = focusSquareThickness / 2 // correction to align lines
perfectly

    let s1 = FocusSquareSegment(name: "s1", width: sl, thickness: st, color:
focusSquareColor)
    let s2 = FocusSquareSegment(name: "s2", width: sl, thickness: st, color:
focusSquareColor)
    let s3 = FocusSquareSegment(name: "s3", width: sl, thickness: st, color:
focusSquareColor, vertical: true)
    let s4 = FocusSquareSegment(name: "s4", width: sl, thickness: st, color:
focusSquareColor, vertical: true)
    let s5 = FocusSquareSegment(name: "s5", width: sl, thickness: st, color:
focusSquareColor, vertical: true)
    let s6 = FocusSquareSegment(name: "s6", width: sl, thickness: st, color:
focusSquareColor, vertical: true)
    let s7 = FocusSquareSegment(name: "s7", width: sl, thickness: st, color:
focusSquareColor)
    let s8 = FocusSquareSegment(name: "s8", width: sl, thickness: st, color:
focusSquareColor)

    s1.position += SCNVector3Make(-(sl / 2 - c), -(sl - c), 0)
    s2.position += SCNVector3Make(sl / 2 - c, -(sl - c), 0)
    s3.position += SCNVector3Make(-sl, -sl / 2, 0)
    s4.position += SCNVector3Make(sl, -sl / 2, 0)
    s5.position += SCNVector3Make(-sl, sl / 2, 0)
    s6.position += SCNVector3Make(sl, sl / 2, 0)
    s7.position += SCNVector3Make(-(sl / 2 - c), sl - c, 0)
    s8.position += SCNVector3Make(sl / 2 - c, sl - c, 0)

    let fillPlane = SCNPlane(width: CGFloat(1.0 - st * 2 + c), height:
CGFloat(1.0 - st * 2 + c))
    let material = SCNMaterial.material(withDiffuse: focusSquareColorLight,
respondsToLighting: false)
    fillPlane.materials = [material]
    let fillPlaneNode = SCNNode(geometry: fillPlane)
    fillPlaneNode.name = "fillPlane"
    fillPlaneNode.opacity = 0.0

    // 2018-02-25 Make the cross-hair for the middle of the
    // focus square
    let xWidth = c
    let xHeight = 0
    let lineOne = FocusSquareSegment(name: "horizontalLine", width: 0.5,
thickness: st, color: UIColor.yellow)
    let lineTwo = FocusSquareSegment(name: "VerticalLine", width: st,
thickness: 0.5, color: UIColor.yellow)
    lineOne.position = SCNVector3(CGFloat(xWidth),CGFloat(xHeight),CGFloat(0))
    lineTwo.position = SCNVector3(Float(xWidth),Float(xHeight),(Float(0)))


    let planeNode = SCNNode()
    planeNode.eulerAngles = SCNVector3Make(Float.pi / 2.0, 0, 0) // Horizontal
    planeNode.setUniformScale(focusSquareSize * scaleForClosedSquare)
    planeNode.addChildNode(s1)
    planeNode.addChildNode(s2)
    planeNode.addChildNode(s3)
    planeNode.addChildNode(s4)
    planeNode.addChildNode(s5)
    planeNode.addChildNode(s6)
    planeNode.addChildNode(s7)
    planeNode.addChildNode(s8)
    planeNode.addChildNode(fillPlaneNode)
    planeNode.addChildNode(lineOne)
    planeNode.addChildNode(lineTwo)
    isOpen = false

    // Always render focus square on top
    planeNode.renderOnTop()

    return planeNode
```

```
  }
}

class FocusSquareSegment: SCNNode {

  enum Direction {
    case up
    case down
    case left
    case right
  }

  init(name: String, width: Float, thickness: Float, color: UIColor, vertical:
Bool = false) {
    super.init()

    let material = SCNMaterial.material(withDiffuse: color,
respondsToLighting: false)

    var plane: SCNPlane
    if vertical {
      plane = SCNPlane(width: CGFloat(thickness), height: CGFloat(width))
    } else {
      plane = SCNPlane(width: CGFloat(width), height: CGFloat(thickness))
    }
    plane.materials = [material]
    self.geometry = plane
    self.name = name
  }

  required init?(coder aDecoder: NSCoder) {
    fatalError("init(coder:) has not been implemented")
  }

  func open(direction: Direction, newLength: CGFloat) {
    guard let p = self.geometry as? SCNPlane else {
      return
    }

    if direction == .left || direction == .right {
      p.width = newLength
    } else {
      p.height = newLength
    }

    switch direction {
    case .left:
      self.position.x -= Float(0.5 / 2 - p.width / 2)
    case .right:
      self.position.x += Float(0.5 / 2 - p.width / 2)
    case .up:
      self.position.y -= Float(0.5 / 2 - p.height / 2)
    case .down:
      self.position.y += Float(0.5 / 2 - p.height / 2)
    }
  }

  func close(direction: Direction) {

    // if the position of the geometry is the same as the
    // plane continue otherwise return
    guard let p = self.geometry as? SCNPlane else {
      return
    }

    // update the width and the height to needed geometry
    var oldLength: CGFloat
    if direction == .left || direction == .right {
      oldLength = p.width
      p.width = 0.5
```

```
    } else {
      oldLength = p.height
      p.height = 0.5
    }
    // change the direction based on the pitch of the phone
    switch direction {
    case .left:
      self.position.x -= Float(0.5 / 2 - oldLength / 2)
    case .right:
      self.position.x += Float(0.5 / 2 - oldLength / 2)
    case .up:
      self.position.y -= Float(0.5 / 2 - oldLength / 2)
    case .down:
      self.position.y += Float(0.5 / 2 - oldLength / 2)
    }
  }
}
```

10.6.11Utilities.swift (extensions to existing classes)

```
// This code was adapted from ARKit-Example-by-Apple
// (https://github.com/gao0122/ARKit-Example-by-Apple)
// Adapted by Sally Britnell on 25/08/17

import Foundation
import ARKit

// Invert the colours of the image
extension UIImage {
  func inverted() -> UIImage? {
    guard let ciImage = CIImage(image: self) else {
      return nil
    }
    return UIImage(ciImage: ciImage.applyingFilter("CIColorInvert"))
  }

  // invert the thumbnail image
  static func composeButtonImage(from thumbImage: UIImage, alpha: CGFloat =
1.0) -> UIImage {
    let maskImage = #imageLiteral(resourceName: "buttonring")
    var thumbnailImage = thumbImage
    if let invertedImage = thumbImage.inverted() {
      thumbnailImage = invertedImage
    }

    // Create a button on a white background with the inverted thumbnail.
    UIGraphicsBeginImageContextWithOptions(maskImage.size, false, 0.0)
    let maskDrawRect = CGRect(origin: CGPoint.zero,
                 size: maskImage.size)
    let thumbDrawRect = CGRect(origin: CGPoint((maskImage.size -
thumbImage.size) / 2),
                  size: thumbImage.size)
    maskImage.draw(in: maskDrawRect, blendMode: .normal, alpha: alpha)
    thumbnailImage.draw(in: thumbDrawRect, blendMode: .normal, alpha: alpha)
    let composedImage = UIGraphicsGetImageFromCurrentImageContext()
    UIGraphicsEndImageContext()
    return composedImage!
  }
}

extension Array where Iterator.Element == CGFloat {

  // return nil if average not set
  var average: CGFloat? {
    guard !isEmpty else {
      return nil
    }

    // iterate through the array floats
    var ret = self.reduce(CGFloat(0)) { (cur, next) -> CGFloat in
      var cur = cur
```

```
      cur += next
      return cur
    }
    let fcount = CGFloat(count)
    ret /= fcount
    return ret
  }
}

extension Array where Iterator.Element == SCNVector3 {
  var average: SCNVector3? {
    guard !isEmpty else {
      return nil
    }

    // set the coordinates to the next
    var ret = self.reduce(SCNVector3Zero) { (cur, next) -> SCNVector3 in
      var cur = cur
      cur.x += next.x
      cur.y += next.y
      cur.z += next.z
      return cur
    }
    let fcount = Float(count)
    ret.x /= fcount
    ret.y /= fcount
    ret.z /= fcount

    return ret
  }
}

extension RangeReplaceableCollection {
  mutating func keepLast(_ elementsToKeep: Int) {
    if count > elementsToKeep {
      self.removeFirst(count - elementsToKeep)
    }
  }
}

// extension utilities to scnode
extension SCNNode {

  // uniformly scale the scnode size
  func setUniformScale(_ scale: Float) {
    self.scale = SCNVector3Make(scale, scale, scale)
  }

  // draw the node on top of other items
  func renderOnTop() {
    self.renderingOrder = 2
    if let geom = self.geometry {
      for material in geom.materials {
        material.readsFromDepthBuffer = false
      }
    }
    for child in self.childNodes {
      child.renderOnTop()
    }
  }

  // determine the pivot point of the node
  func setPivot() {
    let minVec = self.boundingBox.min
    let maxVec = self.boundingBox.max
    let bound = SCNVector3Make( maxVec.x - minVec.x, maxVec.y - minVec.y,
maxVec.z - minVec.z);
    self.pivot = SCNMatrix4MakeTranslation(bound.x / 2, bound.y, bound.z / 2);
  }
}
```

```
extension SCNVector3 {

  init(_ vec: vector_float3) {
    self.init()
    self.x = vec.x
    self.y = vec.y
    self.z = vec.z
  }

  func length() -> Float {
    return sqrtf(x * x + y * y + z * z)
  }

  // return the difference between two scnodes
  func distanceFromPos(pos: SCNVector3) -> Float {
    let diff = SCNVector3(self.x - pos.x, self.y - pos.y, self.z - pos.z);
    return diff.length()
  }


  mutating func setLength(_ length: Float) {
    self.normalize()
    self *= length
  }

  mutating func setMaximumLength(_ maxLength: Float) {
    if self.length() <= maxLength {
      return
    } else {
      self.normalize()
      self *= maxLength
    }
  }

  mutating func normalize() {
    self = self.normalized()
  }

  func normalized() -> SCNVector3 {
    if self.length() == 0 {
      return self
    }
    return self / self.length()
  }

  // Transform the position returning a new vector
  static func positionFromTransform(_ transform: matrix_float4x4) ->
SCNVector3 {
    return SCNVector3Make(transform.columns.3.x, transform.columns.3.y,
transform.columns.3.z)
  }

  func friendlyString() -> String {
    return "(\(String(format: "%.2f", x)), \(String(format: "%.2f", y)),
\(String(format: "%.2f", z)))"
  }

  // center dot
  func dot(_ vec: SCNVector3) -> Float {
    return (self.x * vec.x) + (self.y * vec.y) + (self.z * vec.z)
  }

  // center cross
  func cross(_ vec: SCNVector3) -> SCNVector3 {
    return SCNVector3(self.y * vec.z - self.z * vec.y, self.z * vec.x - self.x
* vec.z, self.x * vec.y - self.y * vec.x)
  }
}

public let SCNVector3One: SCNVector3 = SCNVector3(1.0, 1.0, 1.0)
```

```
func SCNVector3Uniform(_ value: Float) -> SCNVector3 {
  return SCNVector3Make(value, value, value)
}

func SCNVector3Uniform(_ value: CGFloat) -> SCNVector3 {
  return SCNVector3Make(Float(value), Float(value), Float(value))
}

func + (left: SCNVector3, right: SCNVector3) -> SCNVector3 {
  return SCNVector3Make(left.x + right.x, left.y + right.y, left.z + right.z)
}

func - (left: SCNVector3, right: SCNVector3) -> SCNVector3 {
  return SCNVector3Make(left.x - right.x, left.y - right.y, left.z - right.z)
}

func += (left: inout SCNVector3, right: SCNVector3) {
  left = left + right
}

func -= (left: inout SCNVector3, right: SCNVector3) {
  left = left - right
}

func / (left: SCNVector3, right: Float) -> SCNVector3 {
  return SCNVector3Make(left.x / right, left.y / right, left.z / right)
}

func * (left: SCNVector3, right: Float) -> SCNVector3 {
  return SCNVector3Make(left.x * right, left.y * right, left.z * right)
}

func /= (left: inout SCNVector3, right: Float) {
  left = left / right
}

func *= (left: inout SCNVector3, right: Float) {
  left = left * right
}

// SCNMaterial extensions
extension SCNMaterial {

  // set the shading of the material
  static func material(withDiffuse diffuse: Any?, respondsToLighting: Bool =
true) -> SCNMaterial {
    let material = SCNMaterial()
    material.diffuse.contents = diffuse
    material.isDoubleSided = true
    if respondsToLighting {
      material.locksAmbientWithDiffuse = true
    } else {
      material.ambient.contents = UIColor.black
      material.lightingModel = .constant
      material.emission.contents = diffuse
    }
    return material
  }
}

// CGPoint extensions
extension CGPoint {

  init(_ size: CGSize) {
    self.init()
    self.x = size.width
    self.y = size.height
  }

  init(_ vector: SCNVector3) {
```

```
    self.init()
    self.x = CGFloat(vector.x)
    self.y = CGFloat(vector.y)
  }

  func distanceTo(_ point: CGPoint) -> CGFloat {
    return (self - point).length()
  }

  func length() -> CGFloat {
    return sqrt(self.x * self.x + self.y * self.y)
  }

  func midpoint(_ point: CGPoint) -> CGPoint {
    return (self + point) / 2
  }

  func friendlyString() -> String {
    return "(\(String(format: "%.2f", x)), \(String(format: "%.2f", y)))"
  }
}

func + (left: CGPoint, right: CGPoint) -> CGPoint {
  return CGPoint(x: left.x + right.x, y: left.y + right.y)
}

func - (left: CGPoint, right: CGPoint) -> CGPoint {
  return CGPoint(x: left.x - right.x, y: left.y - right.y)
}

func += (left: inout CGPoint, right: CGPoint) {
  left = left + right
}

func -= (left: inout CGPoint, right: CGPoint) {
  left = left - right
}

func / (left: CGPoint, right: CGFloat) -> CGPoint {
  return CGPoint(x: left.x / right, y: left.y / right)
}

func * (left: CGPoint, right: CGFloat) -> CGPoint {
  return CGPoint(x: left.x * right, y: left.y * right)
}

func /= (left: inout CGPoint, right: CGFloat) {
  left = left / right
}

func *= (left: inout CGPoint, right: CGFloat) {
  left = left * right
}

// CGSize extensions
extension CGSize {

  init(_ point: CGPoint) {
    self.init()
    self.width = point.x
    self.height = point.y
  }

  func friendlyString() -> String {
    return "(\(String(format: "%.2f", width)), \(String(format: "%.2f",
height)))"
  }
}

func + (left: CGSize, right: CGSize) -> CGSize {
```

```
  return CGSize(width: left.width + right.width, height: left.height +
right.height)
}

func - (left: CGSize, right: CGSize) -> CGSize {
  return CGSize(width: left.width - right.width, height: left.height -
right.height)
}

func += (left: inout CGSize, right: CGSize) {
  left = left + right
}

func -= (left: inout CGSize, right: CGSize) {
  left = left - right
}

func / (left: CGSize, right: CGFloat) -> CGSize {
  return CGSize(width: left.width / right, height: left.height / right)
}

func * (left: CGSize, right: CGFloat) -> CGSize {
  return CGSize(width: left.width * right, height: left.height * right)
}

func /= (left: inout CGSize, right: CGFloat) {
  left = left / right
}

func *= (left: inout CGSize, right: CGFloat) {
  left = left * right
}

// CGRect extensions
extension CGRect {

  var mid: CGPoint {
    return CGPoint(x: midX, y: midY)
  }
}

func rayIntersectionWithHorizontalPlane(rayOrigin: SCNVector3, direction:
SCNVector3, planeY: Float) -> SCNVector3? {

  let direction = direction.normalized()

  // Special case handling: Check if the ray is horizontal as
  // well.
  if direction.y == 0 {
    if rayOrigin.y == planeY {
      // The ray is horizontal and on the plane, thus all points on the ray
intersect with the plane.
      // Therefore we simply return the ray origin.
      return rayOrigin
    } else {
      // The ray is parallel to the plane and never intersects.
      return nil
    }
  }

  // The distance from the ray's origin to the intersection
  // point on the plane is: normal (0, 1, 0), simplified to:
  let dist = (planeY - rayOrigin.y) / direction.y

  // Do not return intersections behind the start of the ray.
  if dist < 0 {
    return nil
  }

  // Return the intersection point
```

```
  return rayOrigin + (direction * dist)
}

// Float extensions
extension Float {
  enum LengthUnit: Int {
    case Meter = 0
    case CentiMeter
    case Foot
    case Inch
    case Ruler

    var rate:(Float,String) {
      switch self {
      case .Meter:
        return (1.0, "m")
      case .CentiMeter:
        return (100.0, "cm")
      case .Foot:
        return (3.2808399, "ft")
      case .Inch:
        return (39.3700787, "in")
      case .Ruler:
        return (3.0, "尺")
      }
    }

  }
}

extension ARCamera.TrackingState {
  var presentationString: String {
    switch self {
    case .notAvailable:
      return "TRACKING UNAVAILABLE"
    case .normal:
      return "TRACKING NORMAL"
    case .limited(let reason):
      switch reason {
      case .excessiveMotion:
        return "TRACKING LIMITED\nToo much camera movement"
      case .insufficientFeatures:
        return "TRACKING LIMITED\nNot enough surface detail"
      case .initializing:
        return "TRACKING LIMITED\nInitialization in progress"
      case .relocalizing:
        return "relocalizing"
      }
    }
  }
}

extension ARSCNView {

  struct HitTestRay {
    let origin: SCNVector3
    let direction: SCNVector3
  }

  func hitTestRayFromScreenPos(_ point: CGPoint) -> HitTestRay? {

    guard let frame = self.session.currentFrame else {
      return nil
    }

    let cameraPos = SCNVector3.positionFromTransform(frame.camera.transform)

    // Note: z: 1.0 will unproject() the screen position to the far clipping
plane.
    let positionVec = SCNVector3(x: Float(point.x), y: Float(point.y), z: 1.0)
```

```
    let screenPosOnFarClippingPlane = self.unprojectPoint(positionVec)

    var rayDirection = screenPosOnFarClippingPlane - cameraPos
    rayDirection.normalize()

    return HitTestRay(origin: cameraPos, direction: rayDirection)
  }

  func hitTestWithInfiniteHorizontalPlane(_ point: CGPoint, _ pointOnPlane:
SCNVector3) -> SCNVector3? {

    guard let ray = hitTestRayFromScreenPos(point) else {
      return nil
    }

    // Do not intersect with planes above the camera or if
    // the ray is almost parallel to the plane.
    if ray.direction.y > -0.03 {
      return nil
    }

    // Return the intersection of a ray from the camera
    // through the screen position with a horizontal plane
    // at height (Y axis).
    return rayIntersectionWithHorizontalPlane(rayOrigin: ray.origin,
direction: ray.direction, planeY: pointOnPlane.y)
  }

  struct FeatureHitTestResult {
    let position: SCNVector3
    let distanceToRayOrigin: Float
    let featureHit: SCNVector3
    let featureDistanceToHitResult: Float
  }

  func hitTestWithFeatures(_ point: CGPoint, coneOpeningAngleInDegrees: Float,
               minDistance: Float = 0,
               maxDistance: Float = Float.greatestFiniteMagnitude,
               maxResults: Int = 40) -> [FeatureHitTestResult] {

    var results = [FeatureHitTestResult]()

    guard let features = self.session.currentFrame?.rawFeaturePoints else {
      return results
    }

    guard let ray = hitTestRayFromScreenPos(point) else {
      return results
    }

    let maxAngleInDeg = min(coneOpeningAngleInDegrees, 360) / 2
    let maxAngle = ((maxAngleInDeg / 180) * Float.pi)

    let points = features.__points

    for i in 0...features.__count {

      let feature = points.advanced(by: Int(i))
      let featurePos = SCNVector3(feature.pointee)

      let originToFeature = featurePos - ray.origin

      let crossProduct = originToFeature.cross(ray.direction)
      let featureDistanceFromResult = crossProduct.length()

      let hitTestResult = ray.origin + (ray.direction *
ray.direction.dot(originToFeature))
      let hitTestResultDistance = (hitTestResult - ray.origin).length()
```

```
      if hitTestResultDistance < minDistance || hitTestResultDistance >
maxDistance {
        // Skip this feature - it is too close or too
        // far away.
        continue
      }

      let originToFeatureNormalized = originToFeature.normalized()
      let angleBetweenRayAndFeature =
acos(ray.direction.dot(originToFeatureNormalized))

      if angleBetweenRayAndFeature > maxAngle {
        // Skip this feature - is outside of the hit
        // test cone.
        continue
      }

      // All tests passed: Add the hit against this
      // feature to the results.
      results.append(FeatureHitTestResult(position: hitTestResult,
                        distanceToRayOrigin: hitTestResultDistance,
                        featureHit: featurePos,
                        featureDistanceToHitResult:
featureDistanceFromResult))
    }

    // Sort the results by feature distance to the ray.
    // results = results.sorted(by: { (first, second) ->
    // Bool in return first.distanceToRayOrigin <
    // second.distanceToRayOrigin
    //    })

    if results.count < maxResults {
      return results
    }

    // Cap the list to maxResults.
    var cappedResults = [FeatureHitTestResult]()
    var i = 0
    while i < maxResults && i < results.count {
      cappedResults.append(results[i])
      i += 1
    }

    return cappedResults
  }

  func hitTestWithFeatures(_ point: CGPoint) -> [FeatureHitTestResult] {

    var results = [FeatureHitTestResult]()

    guard let ray = hitTestRayFromScreenPos(point) else {
      return results
    }

    if let result = self.hitTestFromOrigin(origin: ray.origin, direction:
ray.direction) {
      results.append(result)
    }

    return results
  }

  func hitTestFromOrigin(origin: SCNVector3, direction: SCNVector3) ->
FeatureHitTestResult? {

    guard let features = self.session.currentFrame?.rawFeaturePoints else {
      return nil
    }
```

```
    let points = features.__points

    // Determine the point from the whole point cloud which
    // is closest to the hit test ray.
    var closestFeaturePoint = origin
    var minDistance = Float.greatestFiniteMagnitude

    for i in 0...features.__count {
      let feature = points.advanced(by: Int(i))
      let featurePos = SCNVector3(feature.pointee)

      let originVector = origin - featurePos
      let crossProduct = originVector.cross(direction)
      let featureDistanceFromResult = crossProduct.length()

      if featureDistanceFromResult < minDistance {
        closestFeaturePoint = featurePos
        minDistance = featureDistanceFromResult
      }
    }

    // Compute the point along the ray that is closest to
    // the selected feature.
    let originToFeature = closestFeaturePoint - origin
    let hitTestResult = origin + (direction * direction.dot(originToFeature))
    let hitTestResultDistance = (hitTestResult - origin).length()

    return FeatureHitTestResult(position: hitTestResult,
                  distanceToRayOrigin: hitTestResultDistance,
                  featureHit: closestFeaturePoint,
                  featureDistanceToHitResult: minDistance)
  }

  /// - Parameter features:
  /// - Returns:
  func fliterWithFeatures(_ features:[FeatureHitTestResult]) -> [SCNVector3] {
    guard features.count >= 3 else {
      return features.map { (featureHitTestResult) -> SCNVector3 in
        return featureHitTestResult.position
      };
    }

    var points = features.map { (featureHitTestResult) -> SCNVector3 in
      return featureHitTestResult.position
    }
    let average = points.average!
    let variance = sqrtf(points.reduce(0) { (sum, point) -> Float in
      var sum = sum
      sum += (point-average).length()*100*(point-average).length()*100
      return sum
      }/Float(points.count-1))
    let standard = sqrtf(variance)
    let σ = variance/standard
    points = points.filter { (point) -> Bool in
      if (point-average).length()*100 > 3*σ {
        print(point,average)
      }
      return (point-average).length()*100 < 3*σ
    }
    return points
  }
}


func createAxesNode(quiverLength: CGFloat, quiverThickness: CGFloat) ->
SCNNode {
  let quiverThickness = (quiverLength / 50.0) * quiverThickness
  let chamferRadius = quiverThickness / 2.0
```

```
  let xQuiverBox = SCNBox(width: quiverLength, height: quiverThickness,
length: quiverThickness, chamferRadius: chamferRadius)
  xQuiverBox.materials = [SCNMaterial.material(withDiffuse: UIColor.red,
respondsToLighting: false)]
  let xQuiverNode = SCNNode(geometry: xQuiverBox)
  xQuiverNode.position = SCNVector3Make(Float(quiverLength / 2.0), 0.0, 0.0)

  let yQuiverBox = SCNBox(width: quiverThickness, height: quiverLength,
length: quiverThickness, chamferRadius: chamferRadius)
  yQuiverBox.materials = [SCNMaterial.material(withDiffuse: UIColor.green,
respondsToLighting: false)]
  let yQuiverNode = SCNNode(geometry: yQuiverBox)
  yQuiverNode.position = SCNVector3Make(0.0, Float(quiverLength / 2.0), 0.0)

  let zQuiverBox = SCNBox(width: quiverThickness, height: quiverThickness,
length: quiverLength, chamferRadius: chamferRadius)
  zQuiverBox.materials = [SCNMaterial.material(withDiffuse: UIColor.blue,
respondsToLighting: false)]
  let zQuiverNode = SCNNode(geometry: zQuiverBox)
  zQuiverNode.position = SCNVector3Make(0.0, 0.0, Float(quiverLength / 2.0))

  let quiverNode = SCNNode()
  quiverNode.addChildNode(xQuiverNode)
  quiverNode.addChildNode(yQuiverNode)
  quiverNode.addChildNode(zQuiverNode)
  quiverNode.name = "Axes"
  return quiverNode
}

func createCrossNode(size: CGFloat = 0.01, color: UIColor = UIColor.green,
horizontal: Bool = true, opacity: CGFloat = 1.0) -> SCNNode {

  // Create a size x size m plane and put a grid texture onto
  // it.
  let planeDimension = size

  var fileName = ""
  switch color {
  case UIColor.blue:
    fileName = "crosshair_blue"
  case UIColor.yellow:
    fallthrough
  default:
    fileName = "crosshair_yellow"
  }

  let path = Bundle.main.path(forResource: fileName, ofType: "png",
inDirectory: "Models.scnassets")!
  let image = UIImage(contentsOfFile: path)

  let planeNode = SCNNode(geometry: createSquarePlane(size: planeDimension,
contents: image))
  if let material = planeNode.geometry?.firstMaterial {
    material.ambient.contents = UIColor.black
    material.lightingModel = .constant
  }

  if horizontal {
    planeNode.eulerAngles = SCNVector3Make(Float.pi / 2.0, 0, Float.pi) //
Horizontal.
  } else {
    planeNode.constraints = [SCNBillboardConstraint()] // Facing the screen.
  }

  // add the cross as a node
  let cross = SCNNode()
  cross.addChildNode(planeNode)
  cross.opacity = opacity
  return cross
}
```

```
// create a square plane and return this with appropriate
// shading
func createSquarePlane(size: CGFloat, contents: AnyObject?) -> SCNPlane {
  let plane = SCNPlane(width: size, height: size)
  plane.materials = [SCNMaterial.material(withDiffuse: contents)]
  return plane
}

// create and return the plane and determine the look of the
// plane
func createPlane(size: CGSize, contents: AnyObject?) -> SCNPlane {
  let plane = SCNPlane(width: size.width, height: size.height)
  plane.materials = [SCNMaterial.material(withDiffuse: contents)]
  return plane
}
```

10.6.12Python script for conversion of Linear-regression models to coreML models

```
% import libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import sklearn
import coremltools

% Setup to import data and create a logfile for output
rowNames = ['age','ethnicity','gender','height','weight']
fileName = 'AEGH.csv'
logFile = open("logFile.txt","w")
dataset = pd.read_csv(fileName, header=1, names=rowNames)
index = 1
name = ""

% Import the data and ensure this is in the right shape to
% build a regression model
while index < 9:
       if index == 1:
              name = "H_"
              X = dataset[['height']]
              features = ['height']
              print(X.shape)
       if index == 2:
              name = "AEGH_"
              X = dataset[['age','ethnicity','gender','height']]
              features = ['age','ethnicity','gender','height']
              print(X.shape)
       if index == 3:
              name = "AEH_"
              X = dataset[['age','ethnicity','height']]
              features = ['age','ethnicity','height']
              print(X.shape)
       if index == 4:
              name = "AGH_"
              X = dataset[['age','gender','height']]
              features = ['age','gender','height']
              print(X.shape)
       if index == 5:
              name = "EGH_"
              X = dataset[['ethnicity','gender','height']]
              features = ['ethnicity','gender','height']
              print(X.shape)
       if index == 6:
              name = "AH_"
              X = dataset[['age','height']]
              features = ['age','height']
              print(X.shape)
       if index == 7:
              name = "EH_"
              X = dataset[['ethnicity','height']]
```

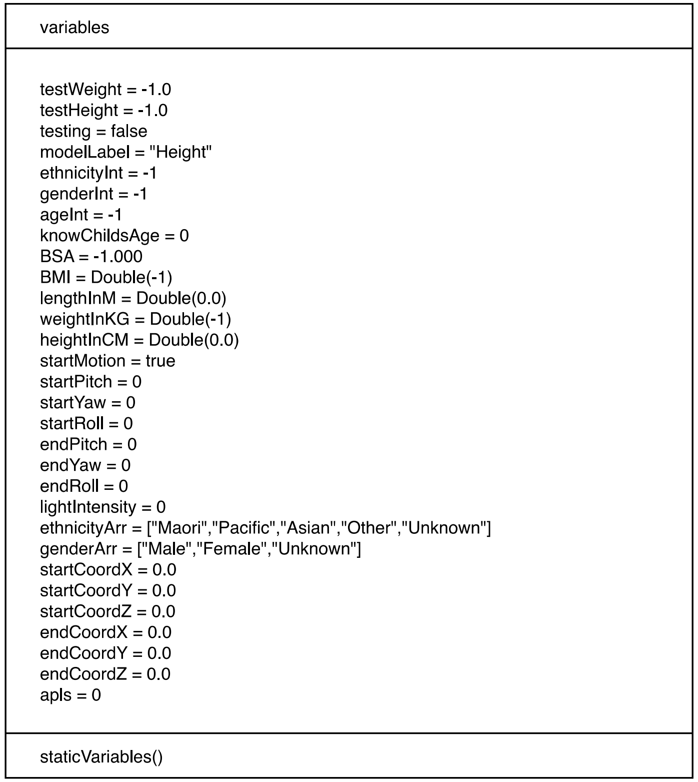
```
            features = ['ethnicity','height']
            print(X.shape)

        if index == 8:
            name = "GH_"
            X = dataset[['gender','height']]
            features = ['gender','height']
            print(X.shape)
        y = dataset['weight']

        % Import the built-in classes
        from sklearn.linear_model import LinearRegression
        from sklearn.model_selection import train_test_split
        from sklearn import metrics

        % Set up the train test split of data
        X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2)
        print(X_train.shape, y_train.shape)
        print(X_test.shape, y_test.shape)

        % Fit the dataset and generate the linear model
        linearModel = LinearRegression().fit(X_train, y_train)
        y_pred = linearModel.predict(X_test)

        % Report information about the regression model to be
% used in assessing fit of the model and write this to
% the log file.
        from sklearn import metrics
        coef = linearModel.coef_
        mse = metrics.mean_squared_error(y_test, y_pred)
        r2 = metrics.r2_score(y_test, y_pred)
        a = 1-(1-r2)
        b = (17051-1)/(17051-(len(name)-1)-1)
        adj_r2 = a*b
        logFile.write(name+" coefficients = "+str(coef)+"\n")
        logFile.write(name+" mse = "+str(mse)+"\n")
        logFile.write(name+" r2 = "+str(r2)+"\n")
        logFile.write(name+" adjusted r2 = "+str(adj_r2)+"\n\n")

        % Convert the model to coreML format
        from coremltools.converters import sklearn
        coreml_model = sklearn.convert(linearModel, input_features=features)

        % Describe the model for visual checking
        print("number of columns in data set "+str(len(X.columns)))
i = 0
        while i < len(X.columns):
            columnName = X.columns[i]
            print(columnName)
            coreml_model.input_description[columnName] = columnName
            i = i+1
        print(coreml_model.input_description)

% Use the model to predict a weight, save this with the
% authors name then save the model and close the log
% file.
        coreml_model.output_description['prediction'] = 'weight in kg'
        coreml_model.author = 'Sally Britnell'
        coreml_model.short_description = name+' model for the WEWW project.'
        saveName=name+"linear_model.mlmodel"
        coreml_model.save(saveName)
        print("file saved "+saveName)
        index = index+1
logFile.close()
```

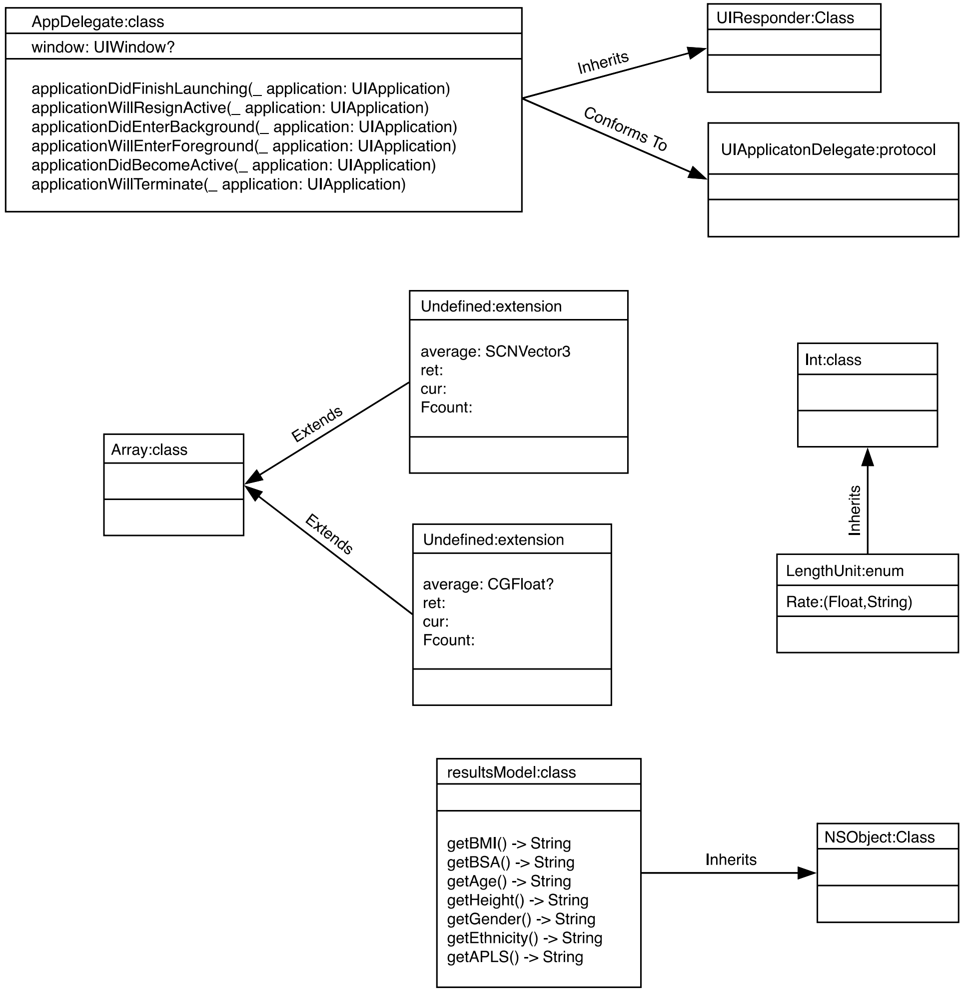
10.6.13TestPredict Application

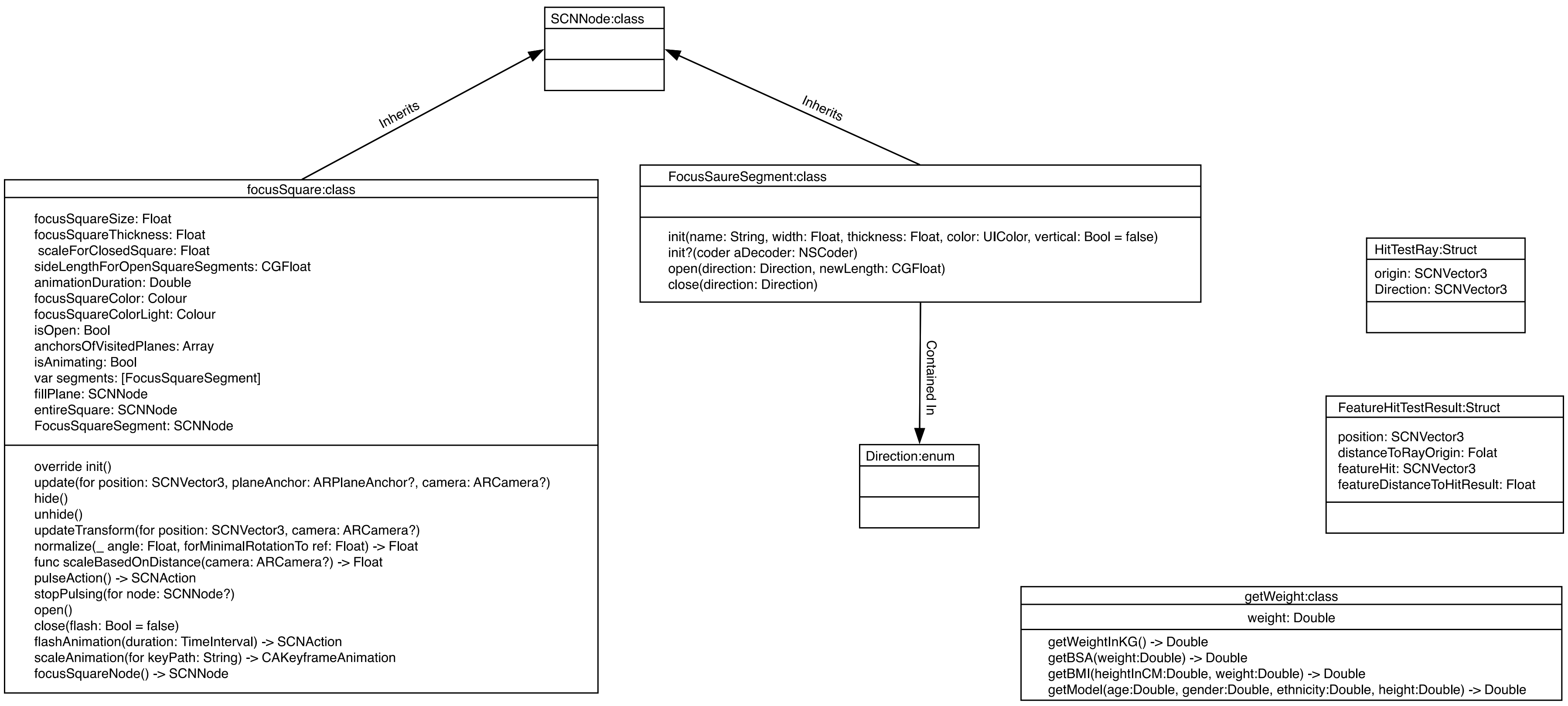
```
// ViewController.swift
// TestPredict
// Created by Sally Britnell on 10/04/19.
// Copyright © 2019 Sally Britnell. All rights reserved.
```

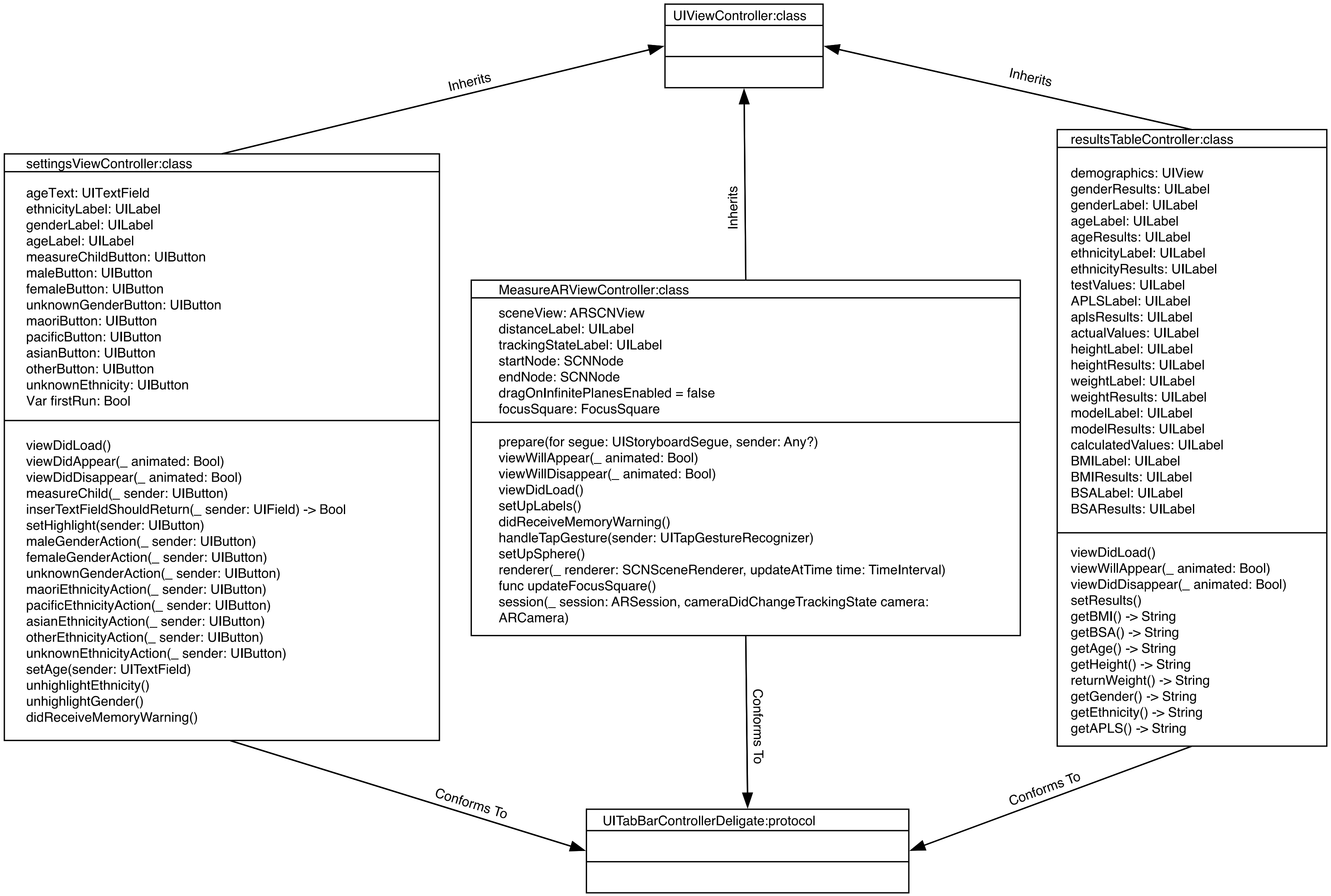
```
import UIKit

class ViewController: UIViewController, UITextFieldDelegate {

  var age: Float = 0.0
  var ethnicity: Int = 0
  var gender: Int = 0
  var height = 0.0

  @IBOutlet weak var AgeResult: UILabel!
  @IBOutlet weak var AgeHeading: UILabel!
  @IBOutlet weak var Results_Label: UILabel!
  @IBOutlet weak var Prediction_Label: UILabel!
  @IBOutlet weak var Height_Label: UILabel!
  let model = AEGH_linear_model()
  @IBOutlet weak var Height_Field: UITextField!
  @IBOutlet weak var Gender: UISegmentedControl!
    @IBOutlet weak var Ethnicity: UISegmentedControl!
    @IBOutlet weak var Age: UISlider!

  override func viewDidLoad() {
    super.viewDidLoad()
    Height_Field.delegate = self
    age = 1
    Ethnicity.isSelected = false
    Gender.isSelected = false
    AgeResult.text = "1 years"
  }

  func textFieldShouldReturn(_ textField: UITextField) -> Bool {
    Height_Field.resignFirstResponder()
    return true
  }

  @IBAction func Gender(_ sender: UISegmentedControl) {
    gender = sender.selectedSegmentIndex
    sender.isSelected = true
    predict()
  }
  @IBAction func Ethnicity(_ sender: UISegmentedControl) {
    ethnicity = sender.selectedSegmentIndex+1
    sender.isSelected = true
    predict()
  }
  @IBAction func Age(_ sender: UISlider) {
    age = sender.value
    let ageString = String(format:"%.0f", age)+" years"
    self.AgeResult.text = ageString
    predict()
  }
  @IBAction func Height_Field(_ sender: UITextField) {
    let heightText = sender.text
    height = Double(heightText!) as! Double
    predict()
  }

  func predict() {

    guard let output = try? model.prediction(age: Double(age), ethnicity: 
Double(ethnicity), gender: Double(gender), height: Double(height))
      else { fatalError("Unexpected runtime error.") }
    Results_Label.text = String(format:"%.2f", output.prediction)
  }
}
```

10.7 Appendix G – UML diagram for the WEWW application






SCNNode:class
Inherits
Inherits
focusSquare:class
focusSquareSize: Float
focusSquareThickness: Float
scaleForClosedSquare: Float
sideLengthForOpenSquareSegments: CGFloat
animationDuration: Double
focusSquareColor: Colour
focusSquareColorLight: Colour
isOpen: Bool
anchorsOfVisitedPlanes: Array
isAnimating: Bool
var segments: [FocusSquareSegment]
fillPlane: SCNNode
entireSquare: SCNNode
FocusSquareSegment: SCNNode
override init()
update(for position: SCNVector3, planeAnchor: ARPlaneAnchor?, camera: ARCamera?)
hide()
unhide()
updateTransform(for position: SCNVector3, camera: ARCamera?)
normalize(_ angle: Float, forMinimalRotationTo ref: Float) -> Float
func scaleBasedOnDistance(camera: ARCamera?) -> Float
pulseAction() -> SCNAction
stopPulsing(for node: SCNNode?)
open()
close(flash: Bool = false)
flashAnimation(duration: TimeInterval) -> SCNAction
scaleAnimation(for keyPath: String) -> CAKeyframeAnimation
focusSquareNode() -> SCNNode
FocusSaureSegment:class
init(name: String, width: Float, thickness: Float, color: UIColor, vertical: Bool = false)
init?(coder aDecoder: NSCoder)
open(direction: Direction, newLength: CGFloat)
close(direction: Direction)
Contained In
Direction:enum
HitTestRay:Struct
origin: SCNVector3
Direction: SCNVector3
FeatureHitTestResult:Struct
position: SCNVector3
distanceToRayOrigin: Folat
featureHit: SCNVector3
featureDistanceToHitResult: Float
getWeight:class
weight: Double
getWeightInKG() -> Double
getBSA(weight:Double) -> Double
getBMI(heightInCM:Double, weight:Double) -> Double
getModel(age:Double, gender:Double, ethnicity:Double, height:Double) -> Double


UIViewController:class
Inherits
Inherits
Inherits
settingsViewController:class
ageText: UITextField
ethnicityLabel: UILabel
genderLabel: UILabel
ageLabel: UILabel
measureChildButton: UIButton
maleButton: UIButton
femaleButton: UIButton
unknownGenderButton: UIButton
maoriButton: UIButton
pacificButton: UIButton
asianButton: UIButton
otherButton: UIButton
unknownEthnicity: UIButton
Var firstRun: Bool
viewDidLoad()
viewDidAppear(_ animated: Bool)
viewDidDisappear(_ animated: Bool)
measureChild(_ sender: UIButton)
inserTextFieldShouldReturn(_ sender: UIField) -> Bool
setHighlight(sender: UIButton)
maleGenderAction(_ sender: UIButton)
femaleGenderAction(_ sender: UIButton)
unknownGenderAction(_ sender: UIButton)
maoriEthnicityAction(_ sender: UIButton)
pacificEthnicityAction(_ sender: UIButton)
asianEthnicityAction(_ sender: UIButton)
otherEthnicityAction(_ sender: UIButton)
unknownEthnicityAction(_ sender: UIButton)
setAge(sender: UITextField)
unhighlightEthnicity()
unhighlightGender()
didReceiveMemoryWarning()
MeasureARViewController:class
sceneView: ARSCNView
distanceLabel: UILabel
trackingStateLabel: UILabel
startNode: SCNNode
endNode: SCNNode
dragOnInfinitePlanesEnabled = false
focusSquare: FocusSquare
prepare(for segue: UIStoryboardSegue, sender: Any?)
viewWillAppear(_ animated: Bool)
viewWillDisappear(_ animated: Bool)
viewDidLoad()
setUpLabels()
didReceiveMemoryWarning()
handleTapGesture(sender: UITapGestureRecognizer)
setUpSphere()
renderer(_ renderer: SCNSceneRenderer, updateAtTime time: TimeInterval)
func updateFocusSquare()
session(_ session: ARSession, cameraDidChangeTrackingState camera: ARCamera)
resultsTableController:class
demographics: UIView
genderResults: UILabel
genderLabel: UILabel
ageLabel: UILabel
ageResults: UILabel
ethnicityLabel: UILabel
ethnicityResults: UILabel
testValues: UILabel
APLSLabel: UILabel
aplsResults: UILabel
actualValues: UILabel
heightLabel: UILabel
heightResults: UILabel
weightLabel: UILabel
weightResults: UILabel
modelLabel: UILabel
modelResults: UILabel
calculatedValues: UILabel
BMILabel: UILabel
BMIResults: UILabel
BSALabel: UILabel
BSAResults: UILabel
viewDidLoad()
viewWillAppear(_ animated: Bool)
viewDidDisappear(_ animated: Bool)
setResults()
getBMI() -> String
getBSA() -> String
getAge() -> String
getHeight() -> String
returnWeight() -> String
getGender() -> String
getEthnicity() -> String
getAPLS() -> String
Conforms To
Conforms To
Conforms To
UITabBarControllerDeligate:protocol