The Pedagogical Approaches Used by Australian Sonographers to Teach Psychomotor Scanning Skills

by

Delwyn Nicholls

BA App Sc (Radiography), Grad Dip (Med US), DMU (Vascular), Grad Dip HEd, Grad Cert HEd. AMS

Thesis
Submitted to Flinders University
for fulfilment of the degree of

Doctor of Philosophy
College of Nursing and Health Sciences

5th May 2020

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

THESIS OUTCOMES

Peer-reviewed publications

Nicholls, D., Sweet, L., Hyett, J. Psychomotor skills in medical ultrasound imaging: an analysis of the core skill set. *Journal of Ultrasound in Medicine*, 2014; 33: 1349-1352.

Nicholls, D., Sweet, L., Skuza, P., Muller, A., Hyett, J. Hyett, J. Sonographer skill teaching practices survey: Development and initial validation of a survey instrument. *Australasian Journal of Ultrasound in Medicine*, 2016; 19(3): 109-117.

Nicholls, D., Sweet, L., Muller, A., Hyett, J. Teaching psychomotor skills in the 21st century: revisiting and reviewing instructional approaches through the lens of contemporary literature. *Medical Teacher*, 2016; 38(10): 1065-1063.

Nicholls, D., Sweet, L., Muller, A., Hyett, J., Ullah, S. Continuing Development and Initial Validation of a Questionnaire to Measure Sonographer Skill-Teaching Perceptions in Clinical Practice. *Journal of Medical Ultrasound*, 2017; 25(2): 82-89.

Nicholls, D., Sweet, L., Muller, A., Hyett, J. A model to teach concomitant patient communication during psychomotor skill development. *Nurse Education Today*, 2018; 60: 121-126.

Book chapter

Nicholls, D. "Approaches to teaching simple and complex psychomotor skills" in *Clinical Education for the Health Professions: Theory and Practice* (2020). Edited by Debra Nestel, Gabriel Reedy, Lisa McKenna and Suzanne Gough (under review)

Conference Presentations

Sonographer skill teaching practices survey (SSTPS): Development and initial validation of a survey instrument. World Congress on Ultrasound in Obstetrics and Gynaecology 2013, International Meeting (Sydney). Poster presentation.

Mastering Skill Acquisition - Maximising teacher/learner synergies. Australasian Society for Ultrasound in Medicine 2015, Annual Scientific Meeting (Sydney).

Teaching psychomotor skills effectively in the 21st century. The World Federation for Ultrasound in Medicine and the American institute of Ultrasound in Medicine 2015, Annual Meeting (Orlando).

SonoSTePs- an Inaugural report of Australian sonographer skill teaching practices. The World Federation for Ultrasound in Medicine and the American institute of Ultrasound in Medicine 2015, Annual Meeting (Orlando).

Is your psychomotor skill teaching approach evidence based? Australasian Society for Ultrasound in Medicine 2016, Annual Scientific Meeting (Sydney).

Achieving skill proficiency, but what about the patient? Australasian Society for Ultrasound in Medicine 2016, Annual Scientific Meeting (Sydney).

The unseen motor movements when teaching and learning a complex psychomotor skill: is physical guidance and modelling the "Holy grail"? Australian and New Zealand Allied Health Professional Education 2017, Annual Meeting (Adelaide).

Teaching a complex psychomotor skill using an 11-step instructional approach. Australasian Sonographers Association 2018, Annual Scientific meeting (Sydney).

Teaching a complex skill in ultrasound: Attempt with caution! The World Federation for Ultrasound in Medicine and Biology 2019, World Congress Meeting (Melbourne).

Australian Sonographer Skill teaching Practices Survey: An inaugural report of the instructional approaches used to teach psychomotor skills. The World Federation for Ultrasound in Medicine and Biology 2019, World Congress Meeting (Melbourne).

The use of physical guidance to teach the scanning skills required for clinical practice: An Australian national survey. World Congress on Ultrasound in Obstetrics and Gynaecology 2019, International Scientific Meeting (Berlin).

ABSTRACT

Medical ultrasound examinations have been performed in Australia for more than five decades, but with little theory or practice evidence for the pedagogical approaches used to teach the psychomotor scanning skills. Performing a medical ultrasound examination requires an operator to use differing upper limb motor movements (at the same or disparate times), and manipulate the ultrasound equipment while they view and interpret the outcome of these actions on a two-dimensional monitor. These skills are referred to as psychomotor scanning skills. The lack of research about how this skill set is taught has restricted the analysis and review of the profession's current teaching practices. Therefore, the goal of this study was to determine what pedagogical approaches were being used by Australian sonographers to teach psychomotor scanning skills.

To achieve the research goal, a 25-question survey instrument, labelled SonoSTePs, was purposefully designed and partially validated. A national cross-sectional cohort survey was then conducted to measure the skill teaching practices of Australian sonographers, using SonoSTePs. A census approach was used to invite 3151 qualified sonographers across Australia who were registered with the Australian Sonographer Accreditation Registry to participate in the research. Quantitative data were analysed using SPSS descriptive and comparative statistics. The open text responses were analysed using content analysis.

A total of 592 sonographers completed the survey, giving a response rate of 19%. The majority of respondents used a two-step skill teaching approach to teach scanning skills, which involved providing a skill demonstration and a narration of the skill steps (86%, $n=$ 450/520), followed by supervised skill practice. Although the majority of respondents (64%) supervised a learner's skill acquisition using numerous short practice sessions of less than 60 minutes, 42% of respondents reported that they used long practice sessions of over 60 minutes and the most common reason for this practice was to compensate the learner for lost skill practice opportunities. Most respondents provided guidance and coaching (92%, $n=$478/519), immediate error correction (79%), and physical guidance (65%) when they taught scanning skills. A large majority of respondents (83%, $n=$403/484) reported that they provided end-task feedback to the learner. However, the feedback was mostly one way from the educator to the learner.

These study findings suggest that Australian sonographers use a two-step model to teach psychomotor scanning skills as well as guidance and coaching, physical guidance, immediate error correction, and the provision of end-task feedback. This thesis is the first to report on the pedagogical approaches used by Australian sonographers to teach psychomotor scanning skills and to provide a synopsis of the suggested pedagogical approaches for teaching complex psychomotor skills. Further research is now needed to explore: (1) whether the two-step instructional model is the optimal approach to maximise a learner's skill acquisition and long-term retention when acquiring, performing, and learning psychomotor scanning skills, and (2) why specific pedagogical approaches were and were not used by the respondents to support the teaching and learning of scanning skills.

DECLARATION

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

…………………………………………..
Signature

6 May 2020

…………………………………………..
Date

ACKNOWLEDGEMENTS

GLOSSARY OF TERMS

AH	Allied health
ALS	Assist learner's scanning
ASA	Australasian Sonographers Association
ASAR	Australian Sonographer Accreditation Registry
ASUM	Australasian Society of Ultrasound in Medicine
B-Mode	Grey shade two-dimensional ultrasound
CO	Cognitive overload
EFA	Exploratory factor analysis
FAST	Focussed Assessment Sonography for Trauma
KMO	Kaiser-Meyer-Olkin
KW2	Weighted kappa
P1	Pilot one
P2	Pilot two
P3	Pilot three
POC	Point-of-Care
POCUS	Point-of-care ultrasound
ML	Maximum likelihood
MSK	Musculoskeletal
SBREC	Social and behavioural research ethics committee
SEF	Skill execution feedback
SonoSTePs	Sonographer skill-teaching practices survey
TAFE	College of technical and further education
TEE	Trans oesophageal echocardiography
TNS	Teach new skill
US	Ultrasound
2D	Two-dimensional
3D	Three-dimensional

PART ONE: THE HISTORY, SKILL SET, AND PEDAGOGICAL APPROACHES USED TO TEACH PSYCHOMOTOR SKILLS IN THE 21ST CENTURY

1   INTRODUCTION

A diagnostic medical ultrasound examination is an imaging method that uses high-frequency sound waves to produce two-dimensional (2D) or three-dimensional (3D) pictures of structures within your body. To be able to realise this imaging potential the operator must be able to perform differing upper limb psychomotor skills to operate the equipment. This chapter provides an overview of the genesis, and then the ongoing development, of the ultrasound profession in Australia and the co-occurring psychomotor skills that are required by operators to use the equipment. The psychomotor skill set to use the equipment progressively evolved in tandem with the technological developments and advancements of the ultrasound machines and transducers. The origins of the medical ultrasound profession have shaped the skill-teaching approaches used by the profession and these pedagogies are reviewed. The chapter concludes by presenting the rationale for undertaking this research, posing the research question, and outlining the aims of the study.

1.1   **Background to the Study**

The essential skill set to perform a medical ultrasound examination requires the operator to be able to move and manipulate a transducer and perform image optimisation and instrumentation. The different manual skills that are used each time an ultrasound is performed, by each upper limb, are referred to as psychomotor scanning skills. The transducer operating limb guides the transducer through a series of many interconnected and multi-dimensional movements; therefore, these movements comprise a complex skill. The console operating limb interacts with a complex keyboard and interface to perform adjustments and calculations, often referred to as knobology skills (Sanders & Hall-Terracciano, 2016). The skills performed by each upper limb can be performed synchronously or asynchronously. When both upper limbs perform differing skills concurrently, they are referred to as dual upper limb tasks (Schmidt, Lee, Winstein, Wulf, & Zelaznik, 2019). In the skill-teaching literature, there is a paucity of knowledge and research about how to teach dual-task upper limb skills. Yet, there is a body of literature which suggests that specific instructional approaches should be used to teach large and multi-dimensional, or complex, skills. There is a lack of educational literature and scholarship about how psychomotor scanning

skills, in particular those performed by the upper limbs, are taught in Australia or elsewhere in the world.

In Australia, medical ultrasound examinations have been performed for approximately five decades. Throughout this period there have been several major technological developments and advancements in the computer and imaging capabilities of the machines. Each iteration of the equipment resulted in further progression and refinement of the imaging and machine technology. During the profession's first twenty years, the skill set to use the equipment was learned by a small group of users. Following each technological advancement, the operator would learn new scanning skills in order to use the new equipment. The skills were learned through trial and error, in research laboratories, or on the job. The cohort tasked with learning the initial, and then the progressively more advanced skill set included scientists, medical specialists, and diversely qualified health and allied health professionals. The health professionals who performed ultrasound examinations would later be called sonographers (Hassal, 2007; McLean, 2016).

In 2016, a Victorian State Government report defined sonographers as "medical imaging professionals within the AH [allied health] sector who operate an ultrasound machine to perform diagnostic medical sonographic examination" (Victorian State Government: Department of Health and Human Services, 2016, p. 11). Sonographers perform a diverse range of diagnostic and therapeutic ultrasound examinations. For example, in the July 2017-2018 calendar year, approximately 10.5 million, general, cardiac, vascular, urological, obstetric and gynaecological, and musculoskeletal (MSK) ultrasound examinations were performed in Australia (Australian Government Department of Human Services, 2017). The cost incurred by the Australian Government to perform these ultrasound examinations in hospitals and private practice was approximately 1.2 trillion dollars or $1,206,305,370.00. The three largest budgets were for general ($379 million), cardiac ($297 million), and MSK ($625 million) ultrasound examinations (Australian Government Department of Human Services, 2017). These data prove that sonographers and other users are performing a significant number of ultrasound examinations in Australia in a 12-month period. However, there remains almost no knowledge about how the Australian sonography profession teaches the foundation scanning skills required to perform these examinations.

Dizon and Grimmer-Somers (2011) point out that the sonography profession is both a young and skills-based vocation; consequently, little attention has been paid to the pedagogical approaches

used to guide the learning of the essential skills which underpin the profession. There is a lack of knowledge and research about how the profession teaches the scanning skills needed for clinical practice in Australia and globally. The absence of empirical research into the pedagogical approaches used by the profession represents a significant gap in the knowledge about the current instructional approaches. The lack of data and credible evidence limits the review and critique of the current teaching practices used by sonographers to teach foundational scanning skills.

1.2 The History of Ultrasound in Australia and How This Has Shaped Many of the Instructional Approaches Used to Teach Scanning Skills

Ultrasound imaging began in Australia during the early to mid-1960s (Hassal, 2007; Gill, 2018). The first machine to be installed into clinical practice was a water bath machine named the Octoson (Australasian Society for Ultrasound in Medicine, 1978). The Octoson was the only machine to use mechanised transducer movements to produce the ultrasound image. Consequently, there was no role for the sonographer to move the transducer to produce an ultrasound image or perform image instrumentation and optimisation skills. With the advent of improved engineering and technological advances the next generation of ultrasound machines required sonographers to physically move the transducer to produce the ultrasound image and they had to adjust the instrumentation panel.

A review of historical records identified the first time that scanning skills were required to operate ultrasound equipment was in the 1970s (Woo, 1998; Griffiths, 2004; Baker, 2005; Hassal, 2007; Davies, 2018b). At this time, the Unirad reticulated arm ultrasound machine (Hewlett, 2018; Westerway, 2018; Davies, 2018b) and then the Advanced Diagnostic Resolution scanner (Woo, 1998; Griffiths, 2004; Baker, 2005; Hassal, 2007; Davies, 2018b) entered the clinical imaging space in quick succession. Both machines were designed differently; however, the common feature of both machines was that the transducer would now be attached to the terminus of a metal arm. This technological advancement would now require the operator to manually move the transducer, in only one direction, to obtain the ultrasound image. However, the engineering of the attachment limited the mobility of the transducer to one flat imaging plane.

The Unirad and Advanced Diagnostic Resolution machines remained in clinical practice for approximately a decade and they were state-of-the art for this era. Operating these machines required the sonographer to perform basic and unrefined scanning skills. This is because the

ultrasound image was created using rhythmical back and forth repetitive movements of the transducer. These actions directed the ultrasound beam down into the body. The returned echoes were processed and a schematic of the anatomy, or a line drawing, was generated. The "image" highlighted the contours and surfaces of the anatomical structures; however, it lacked fine anatomical detail. To obtain an image in the orthogonal plane, the transducer was decoupled from the scanning arm, rotated 90 degrees, and then reattached (Australasian Society for Ultrasound in Medicine, 1976). The steps to generate another image were then repeated. There was no real-time visual or acoustic information being displayed or relayed through speakers as the scan progressed. Therefore, there was no need at this time-point in history to modify or adjust the position of the transducer during image acquisition. The console operating hand performed a simple skill set which involved adjusting a few toggle keys. The next generation of ultrasound equipment would revolutionise the imaging, diagnostic potential, and the skill set needed to use the equipment. This is because the next model of transducer was connected to the machine via a long thin and flexible cable, and this engineering allowed multi-planar movements possible.

In the late 1970s and the early 1980s, a new generation of ultrasound machines would transform the scope of clinical practice in general and cardiac imaging across the world. Real-time grey scale imaging, multi-element, hand-held transducers (as well as the Picker two-dimensional scanner with sector transducers) became readily available (Woo, 1998; Meyer, 2004; Hassal, 2007). The arrival of the sector transducers enabled motion-mode ultrasound, or M-mode, two-dimensional grey-scale echocardiography, and Doppler echocardiography to be performed (Meyer, 2004). Similarly, linear and curvi-linear transducers enabled a diverse array of diagnostic examinations to be performed, e.g. general, vascular, MSK, paediatric, small parts, Doppler, and obstetric and gynaecological ultrasound examinations.

1.3 The Pedagogical Approaches Used by the Profession to Teach Scanning Skills 1960-2019

In Australia, following the introduction of real-time ultrasound and multi-element hand-held transducers, a small cohort of medical specialists, research scientists, and sonographers learned the skill set to scan on the job through trial and error (Hewlett, 2018; Westerway, 2018; Davies, 2018a). At this point in time, the scanning skills that were needed for clinical practice were still being discovered, learned, and mastered. These skills had not yet been described nor chronicled in professional literature. Many years later, these now-learned operators became the educators of the profession and passed on their knowledge to other sonographers and medical specialists in

the clinical space or at professional conferences and workshops (Fonda, 2018a; Griffiths, 2004; Hassal, 2007; Hewlett, 2018; Westerway, 2018).

Hewlett (2018), a pioneer educator, pointed out that, in the 1970s and early 1980s, she taught medical specialists and sonographers to use and operate the ultrasound machines in small groups. A short informal didactic presentation was delivered, which covered the knowledge linked to performing the skill and what the ultrasound image should look like. A portfolio of normal and abnormal ultrasound appearances was collated and taken to the informal teaching sessions (Hewlett, 2018). These images became a valuable teaching and learning resource, because there were few visual records of the sonographic appearances of normal and abnormal anatomical structures. Textbooks and journal articles had not yet been published about this topic. The scanning skills needed to perform an ultrasound examination were basic. They involved the sonographer moving and manipulating the transducer with their transducer operating limb, and performing a limited number of instrumentation functions with their console operating limb. To teach and learn scanning skills, the educator first demonstrated the skill and the learner would then practice the skill (Hewlett, 2018). The learners practised on other group members and the educator would provide feedback on the skill performance. These learners would return to their clinical practices and continue to develop their skill set through on-the-job practice.

In the late 1970s and early 1980s, the introduction of hand-held linear and sector transducers enabled unrestricted probe movements. At this time, the skill set to correctly hold, and then move and manipulate the transducer, was novel and therefore a challenge for all unacquainted sonographers (Davies, 2018a). There was also a dearth of teaching literature which described the terms and techniques needed to use the equipment. To teach the probe manipulation skills, the educator had to first acquaint the learners with the theory and terms used to refer to the corpus of the transducer movements. Next, the educator demonstrated the skill set. Importantly, Davies (2018a) points out that the demonstration of the skill set was initially taught remote to the patient, in a simulated teaching and learning environment. The skills were demonstrated on a pillow which was intended to represent the adult torso (Davies, 2018a). To teach the skill referred to as "sliding" the educator placed the transducer in the middle of the pillow, in a transverse orientation, it was then moved vertically up and down the pillow. Following the skill demonstration, the learner then practised the skill on the make-shift phantom. Davies (2018a) argues that the mastery of this skill set was antecedent to sonographers performing an ultrasound examination.

More than three decades later, Lavender, Coombs, Van Haltren, and Robinson (2016) broadly outlined the educational skill-teaching approach used to image a fetal brain structure. The authors reported on the pedagogical approaches that were used to document the four sections of the corpus callosum at the 18-20-week morphology scan, using sagittal views. First, the learners attended a didactic presentation which reviewed the anatomy, imaging techniques, and scanning skills needed to image the corpus callosum. Then, the sonographer educators provided guidance and instruction during one-on-one training sessions. The purpose of the teaching support was to assist the sonographers with their scanning skills to locate, assess, and document the corpus callosum, using 2D ultrasound. The educators provided technical advice to achieve the combination of transducer movements that were needed to image the curved, and 3D cranial structure. However, the authors do not expand upon the practical teaching approaches that were used to support the sonographer's skill acquisition. Lavender et al. (2016) concluded that with the intensive training sonographers were able to detect the corpus callosum in 71% of cases compared to 23% before training. Furthermore, after training the mean time taken to image all four parts of the corpus callosum was 56.2 seconds. Whereas, before training the structure was only seen in approximately 1 in every 4 fetuses, and to do so took the operators 53.4 seconds (Lavender et al., 2016, p. 717). The study demonstrated that using a pedagogical approach which included (1) attending a didactic lecture, (2) viewing normal and abnormal images of the corpus callosum, and (3) providing expert and facilitated practice support, resulted in improved detection of the corpus callosum (Lavender et al., 2016). Whilst the study highlighted some pedagogical approaches, it is important to point out that not all the steps to teach the skill were described in the article. Nevertheless, this is the first Australian study which identified a diagnostic benefit from providing supported skill training. Lavender et al. (2016) asserts that the skill set to image all sections of the corpus callosum is an example of a complex psychomotor skill.

More recently, Ryan (2017), a sonographer educator, acknowledged that the instructional approach used to teach general trainee sonographers has evolved in his practice group over the years. Ryan (2017, p. 64) proposes that educators or colleagues have moved on from letting a student "have a go", to using an instructional approach which involves sonographers passing on their knowledge and skills to the student. Such a proposal indicates that an ad-hoc approach may have been historically used by some sonographer educators to teach core knowledge and scanning skills. There is little detail provided by Ryan (2017) about the contemporary skill-teaching approaches used by the educators in his practice group.

1.4 A Master-Apprentice Skill-teaching Approach is Sometimes Used as an Instructional Approach to Teach Scanning Skills

Currently, there is little known about whether the sonography profession uses one teaching approach, a mixture of approaches, or a hybrid skill-teaching approach to teach the scanning skills required for clinical practice. There is limited anecdotal evidence to suggest many educators use the master-apprentice model to teach the scanning skills needed for clinical practice. In the field of medicine, the master-apprentice model involves the transmission of knowledge and skills from an experienced and master operator to a less experienced learner (Bleakley, 2002) and skills are usually taught on the job. A criticism of the master-apprentice model is that there is insufficient detail about the pedagogical steps used to teach and then practise a psychomotor skill (Bleakley, 2002). Lake and Hamdorf (2004) have similar misgivings about the use of the master-apprentice skill-teaching model to teach psychomotor skills; this is because the skill is often not taught inclusively of all of the task steps and the practise performance of the learner is frequently not checked and evaluated.

The traditional two-step skill-teaching model is used widely by health professionals as an approach to guide the teaching and learning of psychomotor skills. Archer, van Hoving, and de Villiers (2015, p. 56) outlined that the two-step model involved the educator providing a verbal description of the theory and skills steps as they demonstrated the skill, in simulation, followed by the learner practising the skill and receiving feedback. The description of the two-step skill-teaching model proposed by Archer et al. (2015) is widely accepted in the medical education literature. Orde, Celenza, and Pinder (2010) argue that the two-step skill-teaching approach is more involved than the two steps described by Archer et al. (2015). According to Orde et al. (2010) the two-step model involves the educator providing a slowly narrated skill demonstration followed by the learner replicating the skill steps while they narrate the steps. Next the skill is practiced with a variable amount of supervised skill practice (Orde et al., 2010, p. 1687). This interpretation of the two-step model is not the traditional interpretation of the two-step skill-teaching approach. Therefore, the model posited by Archer et al. (2015) will be used to describe and refer to the two-step skill-teaching model in this thesis.

The process of acquiring scanning skills in the work-place, using a master-apprentice model, is also referred to in the skill-teaching literature as the 'see one, do one, teach one' approach (Archer et al., 2015). Therefore, while the terminology in the health professional literature to refer to a two-step approach to teach psychomotor skills differs, it is important to point out that the pedagogical

approaches used in the master-apprentice model, the traditional two-step model, or the 'see one, do one, teach one' approach' are similar. The Australasian Sonographers Association (ASA) have challenged the appropriateness of the sonography profession to use the master-apprentice model, or "see one, do one, teach one" approach to teach scanning skills and they concluded that it "is a limiting, outdated model" (ASA, 2015, p. 17). Indeed, the ASA have proposed, in a guiding document for sonographer clinical supervision, that the four-step skill-teaching approach proposed by Walker and Peyton (1998) should be used by the profession to teach scanning skills. The ASA do not provide the rationale or research outcomes to support this proposal. Furthermore, the four-step model published by Walker and Peyton (1998) was intended to teach surgical skills. The ASA have not explained why this model has been selected and prioritised ahead of other published skill-teaching models, such as the expanded two-step model described by Orde et al. (2010), the three-step model proposed by Fitts and Posner (1967), or the five-step model outlined by George and Doto (2001). Indeed, there is very little evidence that any of these published models are suited to teaching psychomotor scanning skills. A summary of these different models is shown in Table 1.1

Table 1.1: Summary of variance in teaching models

Teaching model	Steps
Two-step master Apprentice model (Orde et al., 2010; Archer et al., 2015)	1) The educator explains the theory and demonstrates the procedure 2) The student practices the skill with feedback from the educator
Four step model (Walker & Peyton, 1998)	1) The educator performs the skill silently in real time 2) The educator performs the skill explaining each individual step in detail 3) The student describes each step and the educator performs skill 4) The student performs the skill explaining each step and feedback given by educator
Five step approach (George & Doto, 2001)	1) The context and reason for the skill described, to serve as motivation 2) The educator performs the skill silently in real time 3) The educator performs the skill, explaining each individual step in detail. Time is allowed for questions. 4) The student describes each step 5) The student performs the skill with feedback given from educator.

1.5 The Motor Actions Performed by Both Upper Limbs

1.5.1 The transducer operating limb skill set required to use hand-held transducers

The introduction of hand-held transducers required the sonographer to execute a combination of sequenced skill steps. First, the transducer needs to be correctly orientated and held (Bahner, Hughes, & Royall, 2012). Next, coupling gel is applied to the transducer and then placed on the patient's skin to allow the uninterrupted passage of ultrasound into the body, referred to as an acoustic window (Sanders & Hall-Terracciano, 2016). The acoustic window differs for each organ being scanned and changes when patient variation, fetal position and gestational age, or pathology is encountered. Knowledge of these apertures becomes known through guided instruction and practice. Finally, the ultrasound beam is guided through the entire organ in a minimum of two perpendicular, or orthogonal planes. To do this, a combination of transducer movements is required. For many ultrasound examinations the operator uses a variable number of combinations of transducer movements and acoustic windows.

1.5.2 The skills performed by the console operating limb

As mentioned earlier, in the late 1970s to early 1980s, the next generation of ultrasound equipment was released, and the machines were now produced with sophisticated consoles. The ongoing technological advancements meant that the machines were capable of many more clinical applications and functions. Sonographers were now required to use a new skill set that would be performed by the console operating limb. This is because operators now were required to use the knobology and instrumentation controls on the console while the scan was being performed, in order to maximise the clinical capacity of the imaging modality. There was now a novel need for the sonographer to use these function keys to perform image optimisation and instrumentation. The sonographers needed to learn where the core instrumentation and optimisation buttons were located on the console and why it was important to use these controls. There was a need to learn an extensive body of theoretical knowledge, especially ultrasound physics, and then to learn how to practically apply this knowledge. The importance of this skill set was outlined in the competency standards for graduate sonographers by the ASA in 2011 (ASA, 2011, p. 12). Furthermore, the ASA identified that there is parity in the importance of the scanning skills to perform image optimisation and instrumentation, use the transducer, and select the correct acoustic window (ASA, 2011). Therefore, scanning skills, also termed psychomotor skills, are inclusive of the skill sets performed by both upper limbs.

To move the transducer and use the controls on the ultrasound machine the operator needs to use both upper limbs concurrently or asynchronously. The console operating limb performs supporting scanning skills. This limb performed actions which involves adjusting the image optimisation or instrumentation controls on the ultrasound machine. Many of these functions are performed while the transducer operating limb moves the transducer. The supporting scanning skills are continually adjusted throughout an ultrasound examination. The image optimisation functions include adjusting the depth, focal zone position and number, time gain compensation, overall gain, scan angle, and the magnification and zoom controls. These adjustments enable sonographic images of anatomy to be displayed and depicted with the correct grey shades and magnification. However, these optimisation controls do not enable the vascularity of the organ to be assessed, acquire a spectral trace of the flow within a blood vessel, or enable a waveform to be quantified. To assess the organ's vascularity, a range of additional instrumentation functions need to be adjusted and optimised. For example, the sonographer may initiate the use of colour Doppler imaging and then proceed to adjust the size of the colour box, pulse repetition frequency, colour gain, and possibly the wall filter. These functions are adjusted in real-time as the sonographer continues to scan. When the sonographer stops scanning the organ, the console operating limb can then perform the second skill set needed to complete an ultrasound examination.

A break in the scanning enables the image instrumentation functions and controls to be adjusted. At this point in the examination, the sonographer may annotate the frozen image before they capture a stored record of the image. Alternatively, the annotation may be changed in advance to scanning the organ in the orthogonal plane or alternatively the next organ to be scanned. Also, it is while an image is frozen that it can be measured using an auto-calculation package or through the manual application of callipers. Therefore, the console operating limb needs to become fluent in using the text menu, typing on the keyboard, selecting an appropriate calculation package, accessing sub-menus, and placing callipers on the image of structures, or spectral traces, to measure and quantify their volume or other metric. When both groups of skills are either not performed, or they are executed with the incorrect timing and sequencing, this may result in anatomical structures not being optimally assessed, displayed, and measured.

1.5.3 The laws of physics and how they govern the transducer movements

The magnitude of the movements that are used to scan an organ using 2D grey scale imaging vary. Many of the arcs and angles that the transducer is moved through are predicated by the laws of

ultrasound physics. One law requires the beam to be directed at a 90-degree angle of incidence to the organ contour and parenchyma (Fish, 1990; Gill, 2012). Maintaining a 90-degree angle of incidence maximises the reflected echo information returning to the transducer from the scanned tissues (Bahner, Blickendorf, Bockbrader, Adkins, Vira, Boulger, & Panchal, 2016), also referred to as Snell's law (Fish, 1990). The clinical application of this law dictates that combinations of transducer movements are needed to image anatomical structures at 90 degrees insonation. The outcome from using sub-optimal combinations of transducer angles and arcs is that small and/or subtle pathology may not be seen; therefore, the diagnosis may go undetected.

The laws of ultrasound physics are different for pulsed-wave and colour Doppler imaging applications. For example, when using spectral Doppler to assess the haemodynamic properties of blood cells flowing through an organ, or vascular conduit, a 0 to 60 degree angle of insonation is usually preferred (Fish, 1990; Thrush & Hartshorne, 2005). For many vascular examinations the Doppler angle of incidence is required to be kept within a specific range to be able to apply diagnostic criteria. For example, the angle of incidence required to apply diagnostic criteria to evaluate the degree of internal carotid artery stenosis conducted by Neale, Chambers, Kelly, Connard, Lawton, Roche, and Appleberg (1994, p. 644) ranged between 55-65 degrees. A greater than 70% stenosis was detected when the systolic velocity was greater than 270cm/s and the end diastolic velocity was greater than 110 cm/s. Adhering to these technical criteria enables the stenosis to be detected with a sensitivity of 96%, specificity of 91% and an accuracy of 93% (Neale et al., 1994).

The Doppler angle of incidence can be adjusted and optimised. This can be achieved by altering the controls on the instrument panel which in turn electronically 'steers' the ultrasound beam, or physically rocking the transducer which increases or decreases the angle of incidence of the ultrasound beam to the vessel. Frequently, to achieve optimal Doppler angles of incidence both techniques are used in variable combination. Therefore, for those operators who perform vascular and cardiac scans, there is discipline specific knowledge and psychomotor skills that are required for competent clinical practice.

1.5.4   The multidimensional transducer movements needed to perform an ultrasound

The transducer movements used to image the structures in the human body are multi-planar and multi-dimensional because most of the surfaces and tissues are not smooth and flat. Indeed, most organs and tubular structures in the human body are either round, curved, or serpiginous;

furthermore, they are frequently located in fossae which are bowl-shaped. To ensure that the ultrasound beam is directed correctly towards the tissues, which are uneven and dome-shaped, the operator is often required to use multiple acoustic windows and combinations of transducer angles and arcs to view the structure in its entirety. When scanning an organ with ultrasound, a combination of purposefully executed large and then very small movements is required. The larger movements are used to move the transducer to the location of the organ and then they are used to guide the beam through the structure, from top-to-bottom and side-to-side. A combination of smaller movements in the three (X, Y, and Z) planes supplant the larger movements. These movements are made to ensure that the ultrasound beam insonates the tissues at an approximate angle of 90 degrees. When a structure is curved, angled, undulating, or its margins are irregular the combination of transducer movements needed to image the structure change between adjacent sections of the organ. In these clinical scenarios, the combination of multi-planar movements may be novel.

1.6   The Nomenclature Used to Describe the Various Transducer Movements

The nomenclature being used to refer to the six transducer movements to perform an ultrasound examination include rotating, rocking, tilting, sliding, angling, and compression. However, there is a lack of consensus among specialist imaging groups about the intended action for the terms rocking, tilting, and angling or fanning for general (American Institute of Ultrasound in Medicine, 1999 (AIUM); American Institute of Ultrasound in, 2005), cardiac (AIUM, 2005; Brown, Cartwright, Craig, Meredith, Musial, Orzelek, Pacey, Searle, Cox, Halldorf, Jubb, & Ruediger, 2011) and Point-of-Care Ultrasound (POCUS) imaging. Furthermore, Bahner et al. (2016) argue that when teaching POCUS the transducer movements which relate to the term sliding should be further sub-divided and also include the term sweeping. Sweeping refers to "Motion in the short axis of the probe across the body with a consistent angle of insonation at 90° to the target" (Bahner et al., 2016, p. 185), whereas sliding refers to the movement in the other or long axis plane (Bahner et al., 2016). However, the unintended outcome of Bahner et al. (2016) trying to further clarify the transducer action for the term sliding is that there is the potential for further confusion. This is because Bahner et al. (2016, p. 185) state that sliding refers to "motion in the long axis of the probe *across* the body with a consistent angle of insonation at 90° to the target". However, the online video demonstration (that accompanies the article) depicts a differing plane of movement being made to that described in the article. In the video clip, the educator places the transducer against the right lateral rib cage and then proceeds to move it superiorly in the sagittal imaging plane, from

the level of the kidney to the diaphragm. Therefore, this action does not correspond to the authors' written definition for the term sliding. This example also highlights the complexity involved with the task to accurately describe and demonstrate the transducer movements.

The enduring use of inconsistent terms by educators, to refer to the core transducer movements to perform an ultrasound examination, is problematic. Brown et al. (2011) reported that one of the impediments to the teaching and learning process, for cardiac scanning skills, was the inconsistent use of terms by the sonographer educators to refer to transducer movements. There was confusion by the learners when educators used these differing terms to refer to an intended transducer movement. A finding of the pilot research conducted by Brown et al. (2011) was that there was a perception by both the educators and learners that learning efficiencies were realised when consistent terminology was used. Therefore, as ultrasound imaging continues to expand across the globe and is used by disparate health professional groups, a corpus of terminology is required that describes and clearly communicates the intended transducer movements.

1.7 The Real-time Outcomes from Using Dual Upper Limb Movements

1.7.1 Viewing the actions and outcomes of both upper limb movements on a 2D monitor

In the late 1970s, the addition of a 2D monitor on each machine required the operator to develop additional skill-sets to use an ultrasound machine. The monitor provided a source of visual information and feedback that portrayed, in real-time, the outcomes of each upper limb's movements. The operator could now see the real-time outcome of their hand actions that was guiding the transducer movement. Visuo-motor skills, or hand-eye coordination, refer to the ability of the sonographer to intentionally move and manipulate the transducer and observe the expected outcome of the movement on the ultrasound monitor (Nicholls, Sweet, & Hyett, 2014). Visuo-spatial perceptual skills describe the sonographer's ability to correctly interpret the spatial relationships of neighbouring anatomical structures and to create a three dimensional or topographical mental picture of anatomy or pathology, from two dimensional images (Nicholls et al., 2014).

Developed visuo-motor and visuo-spatial skills are essential for the safe execution of an ultrasound examination. For example, to scan an organ the sonographer must first have: (1) the knowledge of the normal sonographic patterns of the organ and surrounding tissues that they are scanning (Bahner et al., 2016); (2) the knowledge of the normal sonographic spatial relationships of the major organs and tissues (Nicholls et al., 2014); and (3) the standard sonographic

anatomical dimensions of the organ or structures that they are scanning (Rumack, Wilson, Charboneau, & Levine, 2011). With further technological advancements and the introduction of pulsed-wave and colour Doppler imaging capabilities, additional scanning skills were required by the operators of the ultrasound machines. The detection of flow pattern abnormalities requires the operator to know the normal and then the abnormal flow profiles and appearances of the organ they were scanning. However, to be able to detect flow changes, the operator first needed to know how to use, optimise, and interpret the imaging outcomes when they applied colour Doppler imaging or acquired spectral Doppler waveforms. Prior to 2014, there was a lack of literature which described the visuo-motor and visuo-spatial skills required to perform an ultrasound examination.

1.7.2   Acoustic feedback

Speakers recessed in the machine console now provided audible information about the blood flow in the sampled blood vessels, when using spectral Doppler. Therefore, acoustic feedback was now possible for those sonographers performing cardiac and vascular examinations. To acquire this acoustic data precise dual upper limb tasks must be performed. The operator's transducer operating limb is positioned to acquire an image of a vascular structure at a precise location, and then to hold the transducer still. While the console operating arm selects the pulsed wave instrumentation and then guides the Doppler line of insonation and sample volume into the correct location within the lumen of the vessel. Following the placement of the sample gate into the vessel, the sonographer "walks" or moves the sample gate along the vessel. The operator simultaneously "listens" to the acoustics of the Doppler signal as they navigate the sample gate through the vessel lumen. When there is a stenosis there will be an increase in the audible frequency at this location. The point of greatest luminal reduction usually corresponds to the highest shifted frequency. At this location, spectral analysis is performed and then the velocity of the red blood cells is quantified using a known Doppler angle (Thrush & Hartshorne, 2005). Therefore, for those sonographers performing cardiac and vascular ultrasound examinations, they need to learn the normal and the abnormal spectral and acoustic profiles of the major vessels that they scan.

At the outset of ultrasound imaging, there was a lack of literature about these laws and how the principles impacted upon the quality of the ultrasound image, the use and applications for Doppler imaging, and the production of artefacts. In contemporary skill-teaching literature, there has been

little attention paid to the combination of transducer movements that are required to assess a structure when it is curved and the inextricable relationship with the governing laws of physics.

1.8   **Defining the Sonographer Educator Practice Role**

The nomenclature that is used to describe the role of a sonographer who assists the skill development of another colleague is variable in Australia. Many sonographers perform a clinical education role without being formally appointed to do so (Brown et al., 2011). Conversely, there is a cohort of sonographers who have a formal educational role. The scope of this role usually includes assisting the development of the knowledge, skills, and professional practice attitudes of their peers and student sonographers. There are at least three titles that have been used to describe a sonographer who performs a formal educational role in clinical practice. The term clinical supervisor, clinical educator, and sonographer educator are used interchangeably in educational literature, conference papers, and by Australian sonography academics. For example, Thoirs et al. (2012), when reporting on the findings of a pilot study to develop the psychomotor skills of novice sonographers, uses the term clinical supervisor as the sole term to refer to the clinical practice role of a sonographer educator. Thoirs, Osborne, Childs, Parange, and Maranna (2016), in a subsequent paper which discusses the importance of using a clinical decision framework to develop student sonographer learning, use the term clinical educator and supervisor interchangeably. Furthermore, Thoirs and Sim (2016, p. 146) also write that the terms of supervisor, mentor, and tutor are synonyms for the role of a clinical educator. Whereas, the ASA, in a professional guideline on clinical supervision, delineates that a clinical supervisor is a credentialed professional who guides and assists a student's education and skill development through instruction and the provision of feedback (ASA, 2015, p. 3). Importantly, the ASA places limitations on the scope of practice for the role of a clinical supervisor, limiting it to the supervision of a student or trainee. Indeed, the governance document points out that the terms of trainee and student may be also used interchangeably (ASA, 2015, p. 3). Additionally, Lavender et al. (2016) explains, in a paper reporting the skill-teaching practices to image the corpus callosum that a sonographer who provides one-on-one education is referred to as a sonographer educator. Therefore, there are several terms that are used by the sonography profession to describe the formal role of supporting and developing the clinical practice skills of students or peers in simulative or authentic practice environments. The term sonographer educator will be used to refer to the collective of these terms in this dissertation. This is because sonographer education

includes the development of the knowledge, skills and professional behaviours of novices, students, and credentialed sonographers.

1.9   **Summary**

Scanning skills are essential to the execution of ultrasound examination. Conducting an ultrasound examination relies on both limbs performing different but inextricably linked and inter-connected skill sets. There are few professions where one upper limb is performing the continuous and dominant skill while the other limb is equally invested but performing asynchronous or synchronous discrete skills. There has been a lack of documentation and scholarship by the sonography profession, about how these scanning, or dual upper limb continuous and discrete, skills are taught. There is limited anecdotal evidence to suggest that the profession still uses a master-apprentice or two-step skill instructional approach to teach the foundation skills required for clinical practice. The lack of scholarship and research about the teaching approaches that are being used limits the critical review and analysis of these approaches and advances in pedagogical practice. Therefore, the purpose of this study is to determine the teaching practices that were being used by the sonography profession, as this knowledge was unknown. Garnering this evidence will then enable the currently used instructional approaches to be compared to the pedagogical approaches that are suggested to teach complex psychomotor skills. In order to improve pedagogical practice, it is important to acquire a body of baseline evidence which captures the skill-teaching behaviours and practices used by Australian sonographers.

There are now many professional cohorts who use ultrasound imaging to support their clinical practice. For example, rheumatology, vascular surgery, cardiology, ophthalmology (Thoirs & Coffee, 2012), midwifery (Swanson, Kawooya, Swanson, Hippe, Dungu-Matovu, & Nathan, 2014), emergency medicine (Alzayedi, Azizalrahman, AlMadi, Althekair, Blaivas, & Karakitsos, 2017), and undergraduate medical ultrasound (Bahner, Adkins, Hughes, Barrie, Boulger, & Royall, 2013) all use ultrasound imaging in their clinical activities. There is also little scholarship about the specific instructional approaches that these disciplines use to teach the scanning skills used to supplant their clinical practice. Therefore, an analysis of the specific teaching approaches that are used by the sonography profession may benefit other disciplines who are also using and teaching ultrasound imaging.

1.10   **Rationale for Study**

Performing an ultrasound examination to a given standard requires an operator to apply and integrate a diverse range of knowledge, skills (communication and psychomotor), and professional practice attitudes (ASA, 2011). There is very little research and literature which has had, as its primary objective, the goal to understand the explicit teaching practices that are being used to teach scanning skills – in particular, those skills performed by the transducer operating limb. To attain credentialing in Australia, sonographers must demonstrate that they are competent in executing scanning skills (ASA, 2011). Qualified sonographers continue to be taught and learn new scanning skills throughout their career, because further technological advancements continue to enter the clinical imaging space new clinical applications are possible. These possibilities coincide with the need for additional and novel scanning skills to be learned. These skills may be taught by a colleague, tutor sonographer, chief sonographer, a subject expert, or specialist doctor. The scanning skills have historically been taught at the bedside and it is unclear which pedagogical approaches are used to teach these skills. More recently, YouTube videos or smartphone applications have also been used as a resource to guide the teaching of the scanning skills required for ultrasound. The pedagogical approach used by the instructors presenting on these platforms has relied upon the use of the two-step skill-teaching approach.

There has been very little attention or inquiry by professional academics, educators, or governing bodies about how the profession teaches the scanning skills required for clinical practice. Furthermore, there has been even less attention given to gaining an understanding about how to teach the acquisition of the concurrent dual upper limb scanning skills required to perform an ultrasound examination. This inaugural research will provide, for the first time, a body of knowledge and data about the specific teaching practices that are being used by the sonography profession to teach these psychomotor skills. The focus of the research is to identify the pedagogical approaches that are being used by a profession to teach psychomotor scanning skills. Importantly, the focus of the thesis is not to isolate how each of the upper limb skill sets are being taught. This is because it is important to establish the broad teaching approaches being used by sonographers before exploring how each of the individual upper limb scanning skills were taught.

The current lack of empirical data and baseline knowledge about the teaching approaches being used by the sonography profession precludes the review and critical analysis of the profession's teaching practices. The chasm of knowledge about this area of clinical health practice is both self-limiting and problematic for the governing regulatory bodies, government, and sonography

profession. This is because the dearth of evidence limits the scrutiny of the pedagogical approaches used and the fiscal outlays and returns by government, professional, and regulatory bodies.

1.11   The Research Question

What pedagogical approaches are used by Australian sonographers to teach psychomotor scanning skills required for clinical practice?

1.12   Research Aims and Objectives

This thesis aims to determine baseline data and information about what are the instructional approaches used by Australian sonographers to teach psychomotor scanning skills.

The primary objectives of this research are to:

1. Conduct the first profession-based research which explores the skill-teaching perceptions, using a survey instrument, of Australian sonographers who teach scanning skills.
2. Determine whether a master-apprentice skill-teaching approach, or two-step model, is used by sonographers to teach psychomotor scanning skills.
3. Identify whether the profession uses heuristic instructional practices to teach psychomotor scanning skills.
4. Summarise the pedagogical approaches used by the profession to teach psychomotor scanning skills, and to compare these teaching practices with the pedagogical approaches that have been suggested to teach complex psychomotor skills.

The project commenced in 2012 and it developed iteratively with each phase being informed by the results of the preceding stage. The dissertation is divided into two parts. Part one consists of six chapters and includes three of the published papers which have contributed to the body of knowledge about the skills that are required to perform an ultrasound, the theory and principles to teach a psychomotor skill, and a review of how to teach the communication skills which are simultaneously required when executing a psychomotor skill. Part two consists of seven chapters and it includes two published papers which outline the research design and approach used to explore the research question, and to present the research outcomes and results from the national cross-sectional cohort survey, after which the limitations of the research are presented and then the research conclusions.

In the first part of the thesis, Chapter 2 discusses and reviews the scope of the psychomotor scanning skills required to perform an ultrasound examination. It identifies and describes the five main skills that are needed to perform an ultrasound. The review highlights that the profession has used incomplete and inconsistent terms to describe the skill set. A definition for a psychomotor skill used by operators of medical ultrasound equipment is provided. Chapter 3 presents a short analysis of simple and complex psychomotor skills. This is because there is emergent literature which describes the need for the sonographer educator to use instructional approaches that is suited to the complexity of the skill they intend to teach. Most of the manual psychomotor skills used by sonographers to perform an ultrasound examination are multi-dimensional; therefore, they are complex and not simple. Chapter 4 examines the pedagogical approaches to teach a complex skill. This chapter reviews the theories and principles related to teaching a psychomotor skill and presents a contemporary 11-step skill-teaching model to guide the teaching and learning of complex and multi-part psychomotor skills, such as those required to perform an ultrasound examination. Chapter 5 outlines how the execution of psychomotor skills on a conscious patient requires health professionals to communicate with the patient as they perform the skill – there was no model found to guide the teaching of the communication skills which co-occur at the time a psychomotor skill is performed. This chapter reviews the theory to teach communication skills and provides a model to guide the teaching and acquisition of the communication skills required by sonographers and other health professionals. Chapter 6 chronicles the results of a scoping review which commenced in 2012 and concluded in February 2019.

The second part of this thesis consists of seven chapters and they chronicle the discourse of the project. Chapter 7 reviews the research design and method. Chapter 8 reports on the iterative and developmental steps that were used to create a profession-specific survey instrument to measure Australian sonographer skill-teaching practices, labelled the SonoSTePs instrument. The results of the first two pilot studies were published and these are presented in Chapter 8. Chapter 9 reviews and discusses the ongoing development and validation of the survey instrument. In this chapter the results of the third pilot are reported and the further changes that were made to the survey instrument are reviewed. Chapter 10 presents the main data and results from undertaking the national sonographer SonoSTePs survey in late 2014. Chapter 11 provides an analysis of the strengths, limitations, and the ongoing refinement and development of the SonoSTePs instrument. Finally, in Chapter 12 the conclusions of the research approach and results are outlined as well as

the recommendations that have been identified from the analysis of the data and the areas of future research.

In the following chapter, the scanning or psychomotor skills that are needed and used to perform an ultrasound examination are reviewed and described. There was a dearth of literature which described these skills at the beginning of this research project; therefore, they were compiled into a corpus of work which provides new knowledge about the type and scope of the skill set used by operators of ultrasound imaging equipment.

2 DEFINING THE SCANNING OR PSYCHOMOTOR SKILLS USED TO PERFORM AN ULTRASOUND EXAMINATION

In 2012, at the commencement of this project, the sonography profession commonly used, and continues to use, the term scanning skills, without explanation to refer the skill set to perform an ultrasound examination. There has been, and continues to be, an ongoing lack of clarity about the skills that authors, and researchers refer to in published papers.

There is no single document which identifies and describes the entirety of the skill set that refers to the corpus of skills used by a sonographer when they perform an ultrasound examination. Indeed, there is a lack of clarity about what should be referred to as psychomotor scanning skills. For example, in the competency standards for entry level graduate sonographers, the ASA identifies that new graduates should be competent in the effective selection and use of a transducer, and be able to perform instrumentation and image optimisation (ASA, 2011). However, the ASA omits to consider that these essential psychomotor scanning skills also include visuo-motor and visuo-spatial skills. This skill set is vital to the graduate's ability to be able to detect some anatomy, such as a retroverted uterus. Furthermore, this skill set, which is inclusive of the cognitive skills as well as the different upper limb movements that are required to perform an ultrasound examination, can also be referred to as a psychomotor skill.

In late 2012, the term psychomotor skill was introduced into the professional vernacular (Thoirs & Coffee, 2012). This was the first identifiable point-in-time that the term was used in published or professional literature. Thoirs and Coffee (2012, p. 703) posited that a psychomotor skill referred to the "skilful manipulation of ultrasound equipment". However, this definition is exclusive of the cognitive skills required to perform an ultrasound. Furthermore, the differing manual skill sets that are performed by each upper limb were not pointed out. Similarly, Gibbs (2014, p. 176) uses the term psychomotor skills but does not identify or expand upon the skill set that the term refers. More recently, Chapman, Hagen, and Gallagher (2016, p. 215) concluded that "currently, there is no clear definition or description of the psychomotor skills used in medical ultrasound imaging". The lack of descriptive literature which describes the gamut of the psychomotor skill set used by the sonography profession is problematic for those sonographer educators tasked with teaching the corpus of skills. Therefore, to address these limitations, the following original peer-reviewed article reviews the core skills that are used to perform an ultrasound examination.

The aim of the paper was to define, identify, and explain the psychomotor skills used by operators of medical ultrasound equipment. The paper focuses on the cognitive processes and the skills performed by the sonographer's transducer operating limb. The article does not explicitly state that the manual skills required to perform an ultrasound should be divided into the skills performed by the transducer operating and console operating limbs. However, as knowledge has advanced and developed on this topic, this distinction and classification of the differing skill sets used by each upper limb has become important. This is because there are suggested pedagogical approaches to use to teach multi-dimensional or complex psychomotor skills. This topic will be covered and further explored in the next chapter.

The following text was published in the peer-reviewed article listed below.

Psychomotor skills in medical ultrasound imaging: An analysis of the core skill set. *Journal of Ultrasound in Medicine,* 2014; *33*(8): 1349-1352. *Citations (47)*.

2.1   Overview

Sonographers use psychomotor skills to perform a medical ultrasound examination. Psychomotor skills describe voluntary movements of the limb, joints and muscles, in response to sensory stimuli and are regulated by the motor neural cortex in the brain. We define a psychomotor skill in relation to medical ultrasound as *"the unique mental and motor activities required to execute a manual task safely and efficiently for each clinical situation"*. Skills in clinical ultrasound practice may be open or closed; the majority of skills used in medical ultrasound imaging are open. Open skills are both complex and multidimensional. Visuo-motor and visuo-spatial psychomotor skills are central components of medical ultrasound imaging. Both skills rely on the learner having a visual exemplar or standard of performance with which to reference their skill performance and evaluate anatomical structures. These are imperative instructional design principles when teaching psychomotor skills.

2.2   Introduction

The skills used to perform a medical ultrasound examination are unique to ultrasonography. Globally, medical ultrasound imaging has been performed for more than 40 years. To date there has been limited research or publications describing the core psychomotor skills used in medical ultrasound imaging. There is, however, theory and practice evidence of psychomotor skills used in clinical practice in other health professions, for example nursing and surgical medicine. This

literature has informed the analysis of the core psychomotor skills used in medical ultrasound imaging.

For each ultrasound performed, fundamental motor skills are used to enable an operator to move and manipulate a transducer in response to sensory information. Explicating and substantiating the theory relevant to ultrasound psychomotor skills provides knowledge and understanding of established and practised skills. Having established the basic theory and constructs of the psychomotor skills used in medical ultrasound imaging this knowledge informs clinical practice skill acquisition and skill-teaching practice. Application of this knowledge is an important starting point for developing educational approaches that teach psychomotor scanning skills. This article presents four key premises for ultrasound teaching: a description of a psychomotor skill; a proposed definition of a psychomotor skill relevant to medical ultrasound imaging; an analysis of the types of skills used in medical ultrasound imaging; and briefly presents how this theory and knowledge may influence psychomotor skill-teaching instructional design practice.

2.3   Psychomotor Skills in Ultrasound Imaging

Psychomotor skills describe voluntary movements of the limb, joints and muscles, in response to sensory stimuli and are regulated by the motor neural cortex in the brain (Doyon & Benali, 2005). The literature demonstrates procedural, technical or task based skills are used interchangeably with psychomotor skills (Kovacs, 1997; Grantcharov & Reznick, 2008). In each health discipline a psychomotor skill is defined by the unique skills that profession uses. Moreover, definitions vary between disciplines, such as surgical medicine, physiotherapy and nursing. In surgical medicine, Kovacs (1997, p. 388) defines a psychomotor skill as "the mental and motor activities required to execute a manual task". Whilst Rose and Best (2005, p. 101) coming from a physiotherapy background, further refine the definition to include being "performed correctly, efficiently and safely". In the nursing literature Bjork (1997, p. 85) states a technical skill is a *"refined pattern of movement or performance based upon and integrated with the perceived demands of the situation".* Amalgamating these statements, we define a psychomotor skill in relation to medical ultrasound as *"the unique mental and motor activities required to execute a manual task safely and efficiently for each clinical situation"*. The word 'correctly', has been purposefully omitted, as the explicit connotation of the word suggests, competence, which is criterion based judgement (Rose & Best, 2005; Dent & Harden, 2009).

2.4 Open and Closed Psychomotor Skills

Psychomotor skills can be classified as open or closed skills (Schmidt, 1975; Milde, 1988). Closed skills are methodically executed each time without variation. Examples include hand washing, and setting up an amniocentesis or paracentesis equipment tray.(Schmidt, 1975; Milde, 1988; DeYoung, 2003). Open skills are more relevant to medical ultrasound; they have a core component that incurs variation each time the skill is executed. This variation may result from a number of factors that include: fetal position or number; bodily habitus; organ orientation and position; pathology, post-surgical change or vascular haemodynamics (Craig, 2016). One example of an open skill is measuring the crown rump length of a 7-week gestational age fetus. The core skill involves measuring the maximal bipolar length of the fetal pole. The variable component of the skill results from the position of the implanted gestational sac and is different for every pregnancy. Therefore, the location of the fetal pole within the gestational sac will vary for each pregnancy. The transducer movements required to obtain the longest length of the fetal pole, will vary for each pregnancy and will be further modified if the uterus is retroverted. The transducer movements required for this skill cannot be rote learnt as they vary each time the skill is executed (Schmidt, 1975; Milde, 1988).

The fundamental psychomotor skills utilised by all sonographers include: i) being able to view three dimensional anatomy in real-time on a two dimensional screen, ii) to move a transducer in multiple planes, iii) to scan an organ in a minimum of two orthogonal planes, and iv) to demonstrate the optimum image of a structure for a given clinical scenario. Central to the execution of this skill set, is the ability to slide, tilt, rotate and fan the ultrasound transducer through a structure, using different acoustic windows (Brown et al., 2011). The transducer movements may be single, sequenced, small or large, adding a further degree of skill complexity. The psychomotor scanning skills utilised in medical ultrasound include visuo-motor and visuo-spatial skills.

2.5 Visuo-motor Skills

Visuo-motor skills or hand eye co-ordination skills evolve from the sonographer having a mental image (visual exemplar) of what the skill should look like for a given clinical scenario (Chenkin, Lee, Huynh, & bandiera, 2008; Wise & Willingham, 2009). A visual exemplar provides a visual standard of performance and is used as a reference image by sonographers when learning a new scanning skill (Milde, 1988; DesCoteaux & Leclere, 1995; Cornford, 1999). Visuo-motor skills use a continual

feedback loop and the visual exemplar is an essential component. Specific limb motor movements guiding the transducer result in a visual image on the monitor. When the visual image of the structure is not clear, sharp and representative of the visual exemplar, a complex motor-neural analysis is undertaken in the brain. The current image is compared and contrasted to the visual exemplar. The necessary changes required to achieve an image to the standard of the visual exemplar are then computed. A motor response is mapped and instigated in the brain. The position of the upper limb and joints are changed through muscle activation, which modifies the transducer position, angle or pressure. This process continues to be updated in real-time, until a visual standard for the skill is achieved (Cornford, 1999; Rose & Best, 2005; Grantcharov & Reznick, 2008). With practice the motor sequences required to move the probe to achieve the visual standard for a given clinical scenario are learned (Ericsson, Krampe, & Tesch-Romer, 1993; Reznick & MacRae, 2006). The clinical scenario may be further complicated by patient bodily habitus, anatomical variation, pathology or organ mobility (Craig, 2016).

When learning psychomotor skills these permutations extrapolate the motor skill learning time-line and make it difficult to learn, replicate and adapt foundational skills (Raman & Donnon, 2008). It is with continued and diligent skill practise that the motor movements and motor plans required to move a transducer, for a given clinical scenario are learned and recalled (Ericsson et al., 1993; Kneebone, Nestel, Vincent, & Darzi, 2007).

The learned motor movements may be, single, sequenced or adaptive, and the process is termed 'motor sequence learning' (Doyon & Benali, 2005). An example of a single motor sequence is the sliding of the transducer from the fetal head down to the fetal pelvis to provide the bony anatomical landmarks to locate the femoral shaft. Scanning the supraspinatus tendon of the shoulder is an example of a sequenced psychomotor skill. Large transducer movements are used to locate the tendon and bony anatomy of the humeral head. Small transducer movements are executed to demonstrate the fibrillar continuity of the tendon fibres to their point of distal insertion. The transducer is moved in multiple planes. The transducer movements to scan the supraspinatus tendon include, angling and tilting whilst simultaneously sliding from anterior to posterior and distal to medial, as the tendon is scrutinized for changes in echogenicity, contour and fibrillar continuity (Gaitini & Dahiya, 2012). A sequenced psychomotor skill may combine any combination of fine and large transducer movements. Whilst an example of an adaptive skill would be rolling a patient into a left lateral decubitus position when a right sided pelvic collection

in noted during an ultrasound examination. The purpose of rolling the patient is to assess whether the fluid is mobile or loculated.

2.6 Visuo-spatial Skills

Visuo-spatial skills describe the sonographer's ability to create a three dimensional or topographical mental picture of anatomy or pathology, from two dimensional images. The mental picture is constructed from scanning an organ in multiple planes, such as, transverse, longitudinal, coronal, radial, anti-radial and oblique planes. The edges of a structure may be further scrutinised by holding the ultrasound transducer in an assigned position, whilst slowly rotating it 360 degrees in real-time. This action is only possible when the size of the structure or pathology is smaller than the beam width of the transducer (Fish, 1990; Gill, 2012). Viewing anatomy from multiples planes, builds a representative three-dimensional mental image of a structure which has, height, width, depth and relationship to other structures. Visuo-spatial skills are central to a sonographer being cognisant of the axis, deviation, rotation and anatomical variation of a structure. These skills alert the sonographer to the anatomical topography, inclusive of anatomical variation. They are contingent upon the sonographer having a visual image or exemplar of the expected sonographic anatomy for each anatomically normal structure assessed. An example of a visuo-spatial skill is the ability to recognise a retroverted uterus from the orientation of the fundal position in the sagittal imaging plane. Perceived aberration in the location or integrity of anatomical structures cues a unique and possibly never rehearsed visuo-motor response. Single or sequenced psychomotor skills effect changes in the transducer position, angle, rotation and probe pressure. These changes are made to ensure the parenchyma or pathology is clearly resolved and the structure is thoroughly interrogated (DesCoteaux & Leclere, 1995). Thus, where anatomical variation or pathology is encountered, visuo-spatial and visuo-motor skills are inextricably linked and form a complex skill set comprised of cognitive, motor, temporal and tactile elements.

2.7 Summary and Conclusion

This article presents the core psychomotor skills used when performing an ultrasound examination. The described psychomotor skills are but one component of the clinical ultrasound examination. However, these skills are the foundation of all medical ultrasound examinations.

Visuo-motor and visuo-spatial skills are central components of medical ultrasound imaging. Both skills rely on the learner having a visual exemplar or standard of performance with which to

reference their skill performance and evaluate anatomical structures. These are imperative instructional design principles when teaching psychomotor skills. The psychomotor skills utilised in medical ultrasound imaging include both complex and open skills. As a result, there are many challenges for those who teach and learn psychomotor skills for medical ultrasound imaging. The limited knowledge and understanding of how single and sequenced psychomotor movements are best learnt in order to execute complex and multidimensional transducer movements to perform rudimentary psychomotor scanning skills, remains an enigma.

2.8   **Summary**

This chapter has identified that there are five skill groups that are required to be able to perform an ultrasound examination, including to:

1) Physically move and manipulate the transducer which results in the directing of the ultrasound beam into the organ or tissues, to be scanned. These movements continue to be adjusted until a clear and sharp image of the organ is achieved. This skill is performed by the transducer operating limb (Nicholls et al., 2014; Bahner et al., 2016).

2) Execute and perform image instrumentation and optimisation (Sonaggera, 2004; ASA, 2011; Ryan, 2017) which are performed by the console operating limb. These skills are integral and essential to the skill set performed by the transducer operating limb. They often support the skills executed by the transducer operating limb.

3) Select and use the optimal acoustic window, or windows, to best view the anatomical structure or organ of interest (Sonaggera, 2004; ASA, 2011; Brown et al., 2011; Ryan, 2017).

4) Develop hand-eye coordination or the ability to intentionally move the transducer and observe the resultant outcome of these movements on a 2D monitor. Where required, to make the necessary adjustments to the transducer to improve or centre the ultrasound image, also referred to as visuo-motor skills (Nicholls et al., 2014).

5) Develop the ability to create a 3D mental picture of the topography of the anatomy, and its relationship to other structures, from the displayed 2D ultrasound images, also referred to as visuo-spatial skills (Nicholls et al., 2014; Chapman et al., 2016).

This is the first corpus of literature which has integrated and described the scanning or psychomotor skills needed to perform an ultrasound. This chapter has presented a definition of a

psychomotor skill. It has elucidated that the execution of a psychomotor skills is reliant upon the sonographer having a visual exemplar or standard of performance to use to guide the movements of the transducer operating and console operating limb actions. The brain processes the visual information on the screen and when the image does not approximate to the standard of performance, or the visual exemplar, the brain instigates either or one upper limb to adjust the scan. This contemporary synthesis of literature makes an original contribution to the knowledge about the cognitive and psychomotor skills that are required to perform an ultrasound examination.

Psychomotor skills may be categorised in several ways. One method is to categorise them according to their complexity. To do so is important, because there is a growing body of research which suggests that an alternative pedagogical approach should be used, by sonographer educators, when they teach complex skills, in contrast to those skills which are categorised as simple. However, there is very little literature in the motor-learning domain and in health education which provide a suitably robust definition of a complex skill. The next chapter provides an original synthesis of the literature to review and describe simple and complex psychomotor skills.

3 THE IMPORTANCE OF BEING ABLE TO CLASSIFY SIMPLE AND COMPLEX PSYCHOMOTOR SKILLS

This thesis aims to identify the pedagogical approaches used by sonographers regarding psychomotor scanning skills required for clinical practice. There is a growing body of literature which suggests the skill-teaching approaches used to teach simple and complex skills differ. Therefore, it is important for educators to first classify the skills that they are going to teach before engaging with students. Currently, there is a dearth of health professional literature which provides the framework to categorise psychomotor skills. However, this step is antecedent to selecting a skill-teaching model to teach the skills required for a learner's clinical practice. Authors from the motor-learning domain have been pioneers in this area. This chapter uses literature drawn from the motor-learning domain and reviews key theories and principles related to classifying the psychomotor skills that are used and taught in clinical practice. Additionally, a small body of health professional literature is drawn upon to critically analyse the tenets which have been adopted to classify simple and complex skills used by sonographers and health professional educators.

3.1 The Rationale for Classifying a Psychomotor Skill

Health professionals use a mixture of open and closed psychomotor skills, and these skills can be further classified as simple or complex. However, there is very little health and medical education literature which outlines how to classify a psychomotor skill. Nevertheless, there is now an emerging body of literature which suggests that the pedagogical approaches that are required to teach simple and complex skills differ (Wulf & Shea, 2002; van Merriënboer, Kester, & Paas, 2006; Brydges, Carnahan, Backstein, & Dubrowski, 2007; Sigrist, Rauter, Riener, & Wolf, 2013). Therefore, health educators from all disciplines require an evidence-based approach to classify the skills that they intend to teach. Indeed, a skill should be classified before it is taught. Furthermore, the process of classification reveals the level of skill complexity; therefore, it informs the pedagogical approaches to use for the given classification (Brydges et al., 2007).

3.2 The Limitations of the Motor-Learning Domain Research Methodology about Research Outcomes

For over a millennium, motor-learning authors have been researching the parameters required to optimise a learner's skill acquisition and cognition. Obtaining reliable and valid results has been an

ongoing challenge for many of the researchers. To ensure that the research design and method was both robust and replicable, many of the experiments used participants performing contrived physical movements. For example, skiing on a simulator in a controlled space (Wulf & Shea, 2002; Schmidt & Lee, 2011; Spittle, 2013; Schmidt et al., 2019), and physical movements such as pulling and reaching tasks (Schmidt & Lee, 2011), or placing a peg in a hole (Spittle, 2013). There were notable research benefits from using skills performed in controlled laboratory environments (Hoffman, 1990; Wulf & Shea, 2002; Spittle, 2013). For example:

1. The austerity of the physical action and the environment in which the skill was performed enabled the research to be replicated.
2. There were no distractions to the operator's attention or for the learner's attention to be split between performing the skill and communicating with the patient.

These demands on attention and working memory are two commonly encountered scenarios in authentic clinical practice encounters.

However, a significant limitation of this body of research is that the skills or tasks that were used in the experiments had very little resemblance to those skills that are performed by many health professionals. Consequently, Hoffman (1990) challenged the results, significance, and intrinsic value of the experiments, performed in sterile environments using skills which did not represent many real world complexities. Yet, the results of these experiments continue to inform many of the pedagogical approaches used to teach psychomotor skills to health professionals. Therefore, the real-world application of this research should now be questioned (Hoffman, 1990), due to its lack of relevance for multi-dimensional skills being taught by health educators to health professionals. There is a poignant argument for researchers to repeat many of the studies using tasks which represent the complexity of the psychomotor skills used by health professionals in real practice. To do so first requires a classification system that enables the skills used by health professionals to be classified as either simple or complex. This is because there is a body of motor-learning theory which suggests that differing pedagogical approaches are required to teach simple and complex skills (Wulf & Shea, 2002; van Merriënboer et al., 2006). Next, the research needs to be conducted in practice settings which replicate the reality and complexity of the clinical space.

3.3   Simple Skills

There is a lack of health professional literature which defines or outlines the characteristics of a simple skill. Without exact definitions and parameters, educators have been left to subjectively determine those skills which are simple and not. Wulf and Shea (2002), from the motor-learning domain, refer to a simple skill as one that involves one degree of freedom. Degrees of freedom refer to the number of joint movements or the combination of joint movements that need to be co-ordinated and controlled to perform the skill (Spittle, 2013). Other attributes which enable a simple skill to be classified include the capability to be taught and learned in one teaching session, and they require insignificant amounts of practice to reach a standard of performance (Wulf & Shea, 2002; Schmidt & Lee, 2011; Spittle, 2013; Schmidt et al., 2019). Another dimension of learning a simple skill is that the teaching and learning process places non-significant demands on a novice's attention and working memory while the skill is being taught and learned (Wulf & Shea, 2002; van Merriënboer et al., 2006; van Merrienboer & Sweller, 2010). There is consensus by the motor-learning authors that these characteristics can be reliably used to classify a simple psychomotor skill.

There is no classification system for health educators and researchers to use or categorise the psychomotor skills used in their professions. The process used to accurately and reliably categorise a psychomotor skill should be transparent, subject to critical review, and defensible. Without this process, the classification of a simple or complex skill is arbitrarily determined; therefore, it will rely on subjective classification and differ among health professionals. Most educators would agree that taking a patient's blood pressure is an example of a simple skill. Additionally, educators and researchers have also asserted that performing tasks such as laryngeal mask airway insertion (Orde et al., 2010) and naso-gastric tube insertion (Krautter, Weyrich, Schultz, Buss, Maatouk, Junger, & Nikendei, 2011), as performed on a manikin, are also examples of a simple psychomotor skill. However, based on the motor-learning domains criteria and metrics used to classify psychomotor skills the latter two examples may not be representative of a simple skill.

3.3.1   Why uniformity in classifying a psychomotor skill is important for the interpretation of research outcomes

There has been an emerging trend by health educational researchers to compare the research outcomes for a given pedagogical approach that involves psychomotor skills of differing complexities. This practice is problematic, because differing pedagogical approaches are required to teach simple and complex psychomotor skills. Therefore, when tasks of dissimilar complexity

are used in the evaluation of a particular pedagogical approach, and the results between the two experiments differ, was the result due to the pedagogical approach or the disparate skill complexity? This question is valid, and it has not been addressed in the literature.

When research results are not reviewed through the critical lens related to task complexity, unexplained relationships between task complexity and pedagogical approaches may go unnoticed or be overlooked. Orde et al. (2010) and Krautter et al. (2011), in separate comparative studies, explored the research outcomes for skill retention and transfer when a "simple skill" was taught using the two-step and four-step instructional approaches. Indeed, Krautter et al. (2011, p. 249) points out in the conclusion that, "It is not clear if our findings can be extrapolated to more complex skills.....". This statement suggests that the researchers consider performing naso-gastric tube insertion on a manikin to be a simple skill. However, are these skills really examples of simple skills? This question certainly needs to be raised. Indeed, the authors of these studies identified that there was no learning benefit from using a four-step teaching approach when compared to the traditional two-step teaching approach, for the outcomes of skill retention and transfer for what they defined as simple skills. Greif, Egger, Basciani, Lockey, and Vogt (2010) likewise compared the two-step and four-step instructional approaches to teach percutaneous needle-puncture cricothyroidotomy and similarly found that there were no learning differences using the two contrasting teaching approaches. While Greif et al. (2010) did not overtly classify the skill to perform percutaneous needle-puncture cricothyroidotomy, they proceed to report in their conclusion that, "Further investigations in more complex skills…[is required]" (p.1696). This statement suggests that the authors think that percutaneous needle-puncture cricothyroidotomy should possibly be classified as a simple or low-level complex skill. A further study by Archer et al. (2015) reported similar findings when using the two-step, four-step, and modified five-step teaching models to teach manual defibrillation using a manikin. In this study Archer et al. (2015) classified the skill as being a moderately complex skill without justifying why they placed the skill in this category. The immediate and two-month post-teaching assessment results demonstrated that there was no statistically significant difference in the skill acquisition or retention, using an alternative pedagogical approach to the two-step model (Archer et al., 2015).

It is questionable whether the tasks used in the previous experiments were representative of a simple or a moderately complex psychomotor skill; this schism has research and integrity implications. This is because the research outcomes derived from using tasks of dissimilar complexity, for a given or comparative pedagogical approach, have limited real-world clinical

application, relevance, and meaning. There is a conspicuous absence of scholarship, research, and debate about the importance of ensuring that psychomotor skills are correctly categorized using a robust and transparent approach.

3.4   **Key Attributes of a Simple Skill**

There are a number of attributes which are associated with learning and executing a simple skill, and they allow them to be categorised relatively easily. For example, a simple skill is not difficult to comprehend and execute, and is usually performed with minimal practice variation (van Merriënboer et al., 2006). Therefore, the steps to perform the skill are limited in number, and the motor movements to perform the skill are visible to the learner when the skill is demonstrated. Consequently, simple skills do not usually involve multiple sub-parts; rather, they are usually limited to one sub-part. Thus, they require small amounts of practice to reach a predefined standard of performance (Wulf & Shea, 2002; van Merriënboer et al., 2006).

An example of a simple psychomotor skill, which contains one sub-part, is preparing a transvaginal probe for an intracavity scan. The theory related to performing the skill and the steps required to perform it are not challenging nor difficult to understand. Therefore, learning simple tasks do not place a large load upon working memory to process the cognitive knowledge and steps and perform the task. In contrast, van Merrienboer and Sweller (2010) propose that teaching skills which are comprised of several sub-parts that each contain greater than nine task-steps has the potential to place great demands on a learner's attention and overload their working or short-term memory. When the skill is new and complex, the learning of several skill sub-parts may exceed the finite capacity of an adult's working memory (Schmidt & Lee, 2011, p. 94). Therefore, most simple tasks involve performing a limited number of steps, usually five to nine, which can be aggregated into one sub-task (van Merriënboer et al., 2006). Amalgamating these descriptions, a psychomotor skill can be categorised as a simple skill when the following attributes are present:

- The task can be taught and learned in one session.

- The task steps and motor movements can be perceived, i.e. are visible, while the skill is demonstrated.

- The whole task is not onerous nor difficult to learn.

- The task can be performed to a pre-defined standard of performance with a small amount of task practice.

- The whole task is comprised of a finite number of skill steps.

- The skill is usually performed with minimal practice variation.

- The skill is most often comprised of nine or less straightforward and chronologically sequenced task steps.

3.5   Complex Skills

Complex psychomotor skills, in comparison to simple skills, present a far greater challenge to correctly categorise. They have been classified by researchers from the motor-learning domain, using a catalogue of metrics for several decades (Wulf & Shea, 2002; Spittle, 2013; Schmidt et al., 2019). Yet, it remains an ongoing difficulty, for researchers in the motor-learning domain, to be able to correctly classify all complex skills. This is because the task characteristics or metrics that have been used to identify complex skills have poor specificity. For example, metrics such as reaction time, response errors/variability, or number of degrees of freedom (Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997; Wulf & Shea, 2002) do not enable the identification and categorisation of all multi-dimensional and complex skills. Consequently, each specific metric may not be present in large enough quantities to rate the skill as being complex throughout the continuum of the entire skill performance.

A further problem is the metrics used by researchers in the motor-learning domain have little application and relevance for health professionals. Most health-related skills are prone to practice variation, making metrics such as reaction time and response errors not useful to determine the complexity of a psychomotor skill. Similarly, the number of degrees of freedom may also not be able to provide a true indication of the task complexity because the instruments used to perform the operation restrict the range of movements, or the number of degrees of freedom, e.g. in the field of laparoscopic surgery (Spruit, Band, Hamming, & Ridderinkhof, 2014, p. 879). Therefore, to use this metric would fail to measure the actual number of the degrees of freedom; consequently, incorrectly classifying the skill. This is not the only discipline where the motor movements of the

operator are restricted because of the equipment or anatomical terrain. In the field of medical ultrasound, for example, the canal of the rectum or the vagina and the surrounding bony architecture restrict the range of transducer movements when scanning the pelvis. Therefore, the number of degrees of freedom would be subverted and not indicative of the real degree of task complexity. It is important to point out that there has been no research about the quantification of the degrees of freedom of the transducer movements made while placed in the vagina or rectum, or many other structures.

Wulf and Shea (2002) and van Merriënboer et al. (2006) assert that several, rather than one, skill attributes are needed to classify a complex skill. The attributes which enable a skill to be classified as being complex include: (1) the skill cannot be taught and learned in one teaching session, (2) the skill involves more than three degrees of freedom, and (3) the research outcomes for the psychomotor skill can be generalised to the real world (also referred to as being ecologically valid). However, these parameters lack relevance to the clinical practice environment of health professionals and sonographers. For example, reaction time is not a useful metric to determine the complexity of a psychomotor skill, and the number of degrees of freedom may not provide a true indication of the complexity of the task. Therefore, for health educators' other metrics are required to enable a complex psychomotor skill to be reliably and reproducibly categorised.

3.6 Determining Which Psychomotor Skills are Complex

Most of the psychomotor skills performed by health professionals, that are genuinely complex, are randomly and arbitrarily classified by health educators and researchers. Mainly, this is attributable to there being no robust classification system available to categorise a complex skill. Consequently, health education authors have used the term complex skill (DeYoung, 2003; Rose & Best, 2005, pp. 105-107; Spruit, Band, & Hamming, 2015, p. 2236) without providing a definition for the term. Therefore, the current classification of a complex psychomotor skill is subjective and inconsistent.

The current motor-learning domain literature suggests that an alternative instructional approach is required when teaching a complex psychomotor skill compared to a simple skill. The process to identify and classify a complex psychomotor skill begins by deconstructing the knowledge, skills (psychomotor and communication), and professional practice attitudes that are needed to perform the task. Raman and Donnon (2008), from the discipline of gastroenterology, identified that performing a colonoscopy was an example of a complex psychomotor skill that involved

cognitive, technical or psychomotor, and process skills. They are the only authors in the health professional literature to outline the attributes of a complex skill, although this was not their main intent. Raman and Donnon (2008) point out that three skill areas or domains help to identify those skills which are complex. The authors identify that the performance of a colonoscopy involves cognitive, technical or psychomotor, and process skills. Therefore, Raman and Donnon (2008) suggest that when a skill involves these three skill domains it can be classified as a complex skill. The dimensions of each domain are outlined below, and they include:

1. Cognitive skills (includes procedural knowledge and the knowledge of the normal and abnormal appearances of the organ system being examined): the steps to perform the procedure; skill or procedural error detection; iterations of decision making; and the when and when-not to perform the skill.

2. Technical skills (or elements of hand-eye co-ordination, gross and fine motor movements): how to manoeuvre and use the equipment; clean and care for the equipment; and complete an examination in a time efficient way.

3. Process skills (or the ability to explain the entire procedure to the patient and provide appropriate post-examination care instructions to the patient): obtain consent; describe the indications and contra-indications for performing the examination; synthesise possible differential diagnosis; and write up a report of imaging findings.

However, there are other additional characteristics that may also help to categorise a complex skill. For example, van Merriënboer et al. (2006) argues that most complex skills are prone to practice variation. Nicholls et al. (2014) conclude that the execution of most complex skills, needed to perform an ultrasound examination, requires the learner to have developed visuo-spatial (mental representation of anatomical structures and objects) and visuo-motor (hand-eye co-ordination) skills. This is because, these skills enable the learner to be able to interpret, analyse, and discriminate the visual and sensory information that is encountered throughout the skill performance Another dimension of performing most complex skills is that they involve dual upper limb tasks to be performed at the same or differing times. There is very little literature which outlines and describes the challenges of learning dual tasks in the health professional literature.

Therefore, the attributes that enable a complex psychomotor skill to be accurately categorised include:

1. The learner requires a large volume of precursory knowledge to be able to conceptualise, perform, modify, or stop when appropriate the execution of the skill (Raman & Donnon, 2008).

2. The learner is required to develop the technical skills to use, manoeuvre, clean and care for the equipment, in a time-efficient way (Raman & Donnon, 2008).

3. The execution of a complex skill usually involves visuo-spatial and/or visuo-motor skills to be able to interpret, analyse, and discriminate the visual and sensory information that is generated throughout the execution of the skill (Nicholls et al., 2014).

4. A complex skill involves process skills or the ability to explain the procedure to the patient (Silverman & Wood, 2004), obtain consent, describe the indications and contra-indications for performing the examination (Bearman, Anthony, & Nestel, 2011) , synthesize possible differential diagnosis, and generate the post examination records and findings in a formal report (Raman & Donnon, 2008).

5. A complex skill is usually prone to practice variation (van Merriënboer et al., 2006).

6. A complex skill involves the learned ability to perform dual upper limb tasks.

The processing of each of these cognitive and knowledge domains places large demands on the learner's attention and the finite capacity of the working memory (van Merrienboer & Sweller, 2010; Leppink & van den Heuvel, 2015). The limitations of the working memory need to be at the forefront of the considerations when a health educator uses a pedagogical approach to teach a complex psychomotor skill. When the execution of a complex psychomotor skill requires concurrent communication with the patient, the skill becomes an even greater challenge to teach and learn. There is literature to suggest that gaining proficiency in the verbal communication skills to communicate with a patient is more challenging for the student than learning the skill itself (Silverman & Wood, 2004; Nicholls, Sweet, Muller, & Hyett, 2018).

These attributes provide clarity about the criteria used to categorise a complex skill and the method is also transparent. Using this approach to justify the classification of a complex psychomotor skill is an important step to perform before commencing the teaching of the skill. Once done, the educator can then select the pedagogical approaches that are best suited to the skill complexity.

3.7 **Summary**

The chapter has demonstrated that the execution of a simple and a complex skill differ in the number of sub-parts and the steps to perform the task. There is limited literature which details the attributes and parameters associated with performing a complex skill. These attributes enable a skill to be categorised as being complex. Following this judgement, the sonographer educator can then use an instructional approach suited to teaching a complex skill. Further research is required to provide data, which is both valid and reliable, for a range of skill complexities that are used by health professionals in clinical practice.

The following chapter outlines the theories, principles, and a suggested pedagogical approach to teach a multi-dimensional and complex skill such as an ultrasound. Literature is drawn from the health disciplines and the motor-learning domain because there is very little literature related to teaching a complex psychomotor skill in medical ultrasound. An 11-step model will be proposed to teach a complex psychomotor skill.

4   THE PEDAGOGICAL APPROACHES TO TEACH A COMPLEX PSYCHOMOTOR SKILL

When this dissertation project was initiated, there was a paucity of literature which described the skills that were required to perform an ultrasound examination. There was even less literature which described the precepts related to how an operator of medical ultrasound equipment was taught, and then learned, the skills that are required to move and manipulate an ultrasound transducer. Before the research question could be addressed, it was a requirement to gain knowledge and understanding of the major motor-learning-domain theory, principles, and hypotheses that related to acquiring and learning a psychomotor skill. It was through this lens that the research question was explored, analysed, described, and defined. In particular, the theories and principles presented by the skill-teaching and motor-learning domain authors helps to articulate the basis for the pedagogical approaches that are required to teach and learn a psychomotor skill.

A large body of literature related to the topic of motor-learning and control exists. This thesis does not provide an extant review of the many theories, principles, or hypotheses related to learning a psychomotor skill. In particular, the thesis does not extensively discuss some of the more nuanced and controvertible debate regarding the limitations of Adam's Closed loop theory (Schmidt & Lee, 2011, pp. 440-441) or review the discussion which surrounds the use of the term 'general motor program', as it is deemed that this is beyond the remit of this dissertation. This chapter will include a review and discussion of the major and widely accepted motor-learning theories and principles related to teaching and learning complex psychomotor skills. This foundation knowledge informs the pedagogical steps used to teach a psychomotor skill, explains and demystifies many of the motor-learning processes (including how the brain functions when learning a psychomotor skill), and is antecedent to being able to understand the limitations of the brain when learning novel and complex psychomotor skills.

The following peer-reviewed published paper outlines the theory and principles to teach a psychomotor skill. The pedagogical approaches that are required to teach a multi-dimensional complex skill, such as ultrasound imaging, are reviewed and critically analysed. A suggested 11-step skill-teaching approach has been presented to assist educators to teach complex skills. There is very little literature which outlines a pedagogical approach specifically to teach complex skills. Importantly, the model described has not been evaluated in clinical practice to assess a learner's

skill retention, recall, and learning, beyond the practise period. This is an important and future step needed to validate the model to teach complex skills.

The following text was published in the peer-reviewed article listed below.

Teaching psychomotor skills in the 21st century: revisiting and reviewing instructional approaches through the lens of contemporary literature. Nicholls, D., Sweet, L., Muller, A., & Hyett, J. *Medical Teacher,* 2016; 38(10): 1065-1063. *Citations (32).*

4.1 **Abstract**

A diverse range of health professionals use psychomotor skills as part of their professional practice roles. Most health disciplines use large or complex psychomotor skills. These skills are first taught by the educator then acquired, performed, and lastly learned. Psychomotor skills may be taught using a variety of widely accepted and published teaching models. The number of teaching steps used in these models varies from two to seven. However, the utility of these models to teach skill acquisition and skill retention are disputable when teaching complex skills, in contrast to simple skills. Contemporary motor-learning and cognition literature frames instructional practices which may assist the teaching and learning of complex task-based skills. This paper reports eleven steps to be considered when teaching psychomotor skills.

4.2 **Introduction**

Teaching health practitioners the core psychomotor skills required for clinical practice remains an ongoing challenge in the 21st century. Most psychomotor skills are unique to each discipline and are required to perform specific clinical practice roles to deliver competent patient care. These skills are first taught using a stepped instructional approach and then acquired, performed, and learned by the student. A learned skill is retained beyond the practice period; it can be recalled and executed competently in a variety of clinical settings (Kantak & Winstein, 2012). In the 20th century, motor-learning theorists posited the steps to teach and learn a manual task or psychomotor skill (Fitts, 1962; Simpson, 1966; Fitts & Posner, 1967; Harrow, 1972; Gentile, 1972). Subsequently, several authors have published models which are permutations of these enduring theoretical principles (Payton, 1986; Walker & Peyton, 1998; George & Doto, 2001). The primary tenet of the skill-teaching literature asserts that skills are best learnt using a sequenced and stepped teaching approach. This dogma guides the method used to teach either a simple or complex manual task. However, most skills used by health professionals are complex. For the

purposes of this paper, we suggest a complex task is comprised of many skill sub-parts. The execution of each skill sub-part involves five to nine skill steps (van Merriënboer et al., 2006). Multi-part tasks are difficult to teach, learn, and be retained by the student. Despite this, the published models continue to be used to teach both simple and complex skills in the health disciplines, even though there is a dearth of evidence evaluating their effectiveness.

The efficacy of using a stepped instructional model to teach psychomotor skills continues to be debated. When using the five-step George and Doto (2001) model to teach a simple dental skill, Virdi and Sood (2011) reported that after one skill attempt, novices were able to perform the task. Furthermore, Wang et al (2004) found that the Walker and Peyton (1998) four-step model enhanced simple skill acquisition by fourth year medical students, to learn a simple interrupted stitch. In contrast, some studies have been unable to report improved learning outcomes, such as skill acquisition and retention, when using a skill-teaching model to teach a moderately complex or complex skill. Archer et al (2015) compared skill-teaching models involving two steps, four steps, and a modified five step approach to perform manual defibrillation of a manikin with ventricular fibrillation, and identified no significant differences in skill acquisition and retention after two months. These findings corroborate studies which similarly explored the use of the four-step skill-teaching model to teach complex skills such as: laryngeal mask airway insertion (Orde et al., 2010), needle cricothyroidotomy (Greif et al., 2010), and gastric tube insertion on a manikin (Krautter et al., 2011). A paucity of evidence, however, on skill-teaching and learning outcomes limits meaningful analysis and interpretation of the data. Nevertheless, there is a suggestion the four-step and five-step models have limited utility to assist skill acquisition and retention when teaching large and complex tasks.

A review of contemporary motor-learning literature shows there are silos of knowledge and research which serve to inform and modify the mechanistic steps used to teach psychomotor skills in the 21st century. These instructional processes are relevant when teaching large and complex skills and they include: cognitive task analysis or breaking down a large or complex skill into component knowledge and skill parts well in advance of the teaching session (Phipps, Meakin, Beatty, Nsoedo, & Parker, 2008; Jabbour, Reihsen, Sweet, & Sidman, 2011); restricting the number of skills taught in any one teaching session to limit the effects of cognitive overload when learning a *new* skill (van Merrienboer & Sweller, 2010; Young, van Merrienboer, Durning, & Cate, 2014; Leppink & van den Heuvel, 2015); dissuading educator guidance and coaching to a learner during skill practice and rehearsal (Walsh, Ling, Wang, & Carnahan, 2009; Leppink & van den Heuvel,

2015); providing immediate error correction when a skill is declared (verbalised) or practiced incorrectly (Kovacs, 1997; Kantak & Winstein, 2012); providing multiple short skill practice opportunities to ultimately learn the skill components (Foy, 2009; Wise & Willingham, 2009; DeBourgh, 2011); and lastly ensuring the learner receives skill practice feedback or knowledge of results at the conclusion of an observed skill performance (Ende, 1983; Poole, 1991; Walsh et al., 2009). An integrated instructional model to teach multi-part psychomotor skills, one which results from weaving contemporary teaching principles into the theoretical principles, may prove in the longer term more effective, than current approaches, to teach the complex psychomotor skills required for clinical health practice.

This paper reviews the historical steps which underpin psychomotor skill acquisition and learning and evaluates these in the context of more contemporary literature, with the aim of re-defining the rationale and instructional approach used to teach complex psychomotor skills for clinical practice.

4.3   Teaching a Psychomotor Skill

The skill-teaching models currently used in clinical practice are based on long-standing and widely accepted motor-learning theory originally posited by Fitts (1962) and thereafter Simpson (1966), closely followed by Fitts and Posner (1967). These authors and others concur that psychomotor skills are acquired in stages using a sequenced skill-teaching approach. Over the years, disciplines such as surgery (Kneebone, 1999; Hamdorf & Hall, 2000; Kneebone, Kidd, Nestel, Asvall, Paraskeva, & Darzi, 2002; Lake & Hamdorf, 2004; Reznick & MacRae, 2006), anaesthetics (Castanelli, 2009), gynaecology (Hammond & Karthigasu, 2006), nursing (Cornford, 1999; Jamison, Hovancsek, & Clochesy, 2006), dentistry (Virdi & Sood, 2011), physiotherapy (Payton, 1986), colonoscopy (Raman & Donnon, 2008), internal medicine (Ramani, 2008), and emergency medicine (Greif et al., 2010) have used teaching models premised on this long standing literature that outlines the tenets of psychomotor acquisition or the motor-learning domain. These disciplines use skill-teaching models with a variable number of skill steps to teach manual tasks. The salience of these models in supporting the instructional steps to teach simple psychomotor skills is acknowledged, but so too is the value of the contemporary literature which describes new knowledge that is relevant to teaching a complex psychomotor skill. The process of integrating this literature has resulted in a series of instructional approaches which, we suggest, are applicable when teaching and learning complex psychomotor skills. The steps to teach a complex

psychomotor skill (see Table 4.1) are presented through a contemporary lens to explain the rationale for adopting this method of teaching a complex skill. The next section will explore each of these skill steps in more detail.

Table 4.1: The educational steps required to teach a complex psychomotor skill

Skill Step	Educator behaviour
Task analysis and cognitive load awareness	Prior to the skill-teaching session, break down the task or knowledge required to perform the skill into chunks. Itemise the steps to teach each skill chunk and this should contain no more than nine sequenced steps (preferably seven) in any one teaching session (refer to Figure 4.1)
Identifying learner skill level and learning needs	Ascertain learners' needs and prior knowledge and skill level to focus the skill-teaching session.
Pre-skill conceptualisation (sensory norms)	Describe when and when not to perform the skill. Review *all* key information linked to competent skill execution (including equipment handling) and what the task should look, sound, and feel like.
Demonstration – visualisation (visual standard of performance)	The educator silently demonstrates the skill with the correct sequence and timing. A silent video clip of the skill may also serve as a synchronous or asynchronous learning tool for this step.
Demonstration – verbalisation	The educator repeats the skill demonstration whilst describing the demonstrated skill steps to the learner.
Immediate error correction	During practice, the educator corrects all narrated or executed skill errors immediately as they occur.
Limit guidance and coaching	Minimise verbal guidance and coaching. Withhold feedback until the conclusion of the task.
Verbalisation – execution	The learner describes the skill steps with the correct skill sequence and timing in advance to the *educator* executing the skill. Corrects incorrectly rehearsed skill step(s) as they occur.
Verbalisation – performance	The learner describes each skill step before they execute the task step. The educator withholds feedback.
Skill practice	Skills are developed using multiple, short practice sessions of less than 60 minutes in duration.
Post-skill-execution feedback	The educator provides feedback at the conclusion (terminal) of the skill performance.

4.4   Task analysis and cognitive load awareness

When developing a process to teach a new skill, it is important to remember that cognitive load theory emphasises the limitation of the working memory when learning complex tasks (Sweller, 1993). The instructional approaches an educator can use to limit cognitive overload include: undertaking task analysis (Phipps et al., 2008; Jabbour et al., 2011); limiting the number of skills

taught in any one teaching session to a range of five to nine (van Merrienboer & Sweller, 2010; Young et al., 2014); and limit dividing the learner's attention between two concurrent information sources (Leppink & van den Heuvel, 2015).

Unlike long-term memory, working memory is finite and limited in capacity (van Merrienboer & Sweller, 2010; Young et al., 2014). This limitation has ramifications when teaching large or complex skills because the working memory quickly becomes overloaded when the volume of information being taught in one session is large or the duration of attention required to learn the task is lengthy (Leppink & van den Heuvel, 2015). While teaching a complex skill, working memory can become overloaded when: the task is novel and therefore the brain must concurrently process multiple sources of information (theoretical, visual, auditory and tactile elements); the learner's attention is divided between learning the skill and processing extraneous information provided by the educator; or the task is multi-part and they are taught in one session (Young et al., 2014; Leppink & van den Heuvel, 2015).

Task analysis – also referred to cognitive task analysis (Jabbour et al., 2011) – is one instructional approach the educator can perform, to limit cognitive overload (Leppink & van den Heuvel, 2015) to improve the performance of technical skills and equipment handling for complex tasks (Sullivan, Brown, Peyre, Salim, Martin, Towfigh, & Grunwald, 2007; Jabbour et al., 2011). This strategy involves breaking a large or complex skill into sub-parts (Phipps et al., 2008; Jabbour et al., 2011) and then further dissecting each sub-part into a range of five to nine discrete items (van Merrienboer & Sweller, 2010; Leppink & van den Heuvel, 2015). As a guide, van Merriënboer and Sweller (2010) subscribe to teaching no more than seven skill steps in any one teaching session and when there are more than this for a sub-component the task should be taught in two parts. This task analysis occurs *prior* to the commencement of the skill-teaching session (Sullivan et al., 2007; Phipps et al., 2008; Jabbour et al., 2011). The benefit of performing task analysis is information is placed into manageable learning chunks and this has the effect of minimising the steep learning curve and cognitive demands placed on working memory (Leppink & van den Heuvel, 2015), especially when learning a new and complex psychomotor skill (Hamdorf & Hall, 2000; Sullivan et al., 2007; Lammers, Davenport, Korley, Griswold-Theodorson, Fitch, Narang, Evans, Gross, Rodriguez, Dodge, Hamann, & Robey, 2008; Castanelli, 2009; Razavi, Karbakhsh, Panah Khahi, Dabiran, Asefi, Shahrak, & Afrooz, 2010). Leppink and Heuvel (2015) argue that overloading a learner's working memory results in cognitive overload and the negative effects are compelling. The consequences of not using a teaching approach which limits the effects of

cognitive overload are persuasive and include: asynchronous and erratic skill performance; a protracted skill learning time-line; and erosion of a learner's confidence (van der Linden, 2010; Blissett, Cavalcanti, & Sibbald, 2012; Young et al., 2014).

Performing an early first trimester pregnancy dating scan is one example of a complex psychomotor skill. The task can be broken down into six knowledge and skill sub-parts, as seen in Figure 4.1. Each sub-component is further deconstructed into discrete task or information elements. The skill steps to each sub-component are taught and learned separately (Aggarwal, Grantcharov, Moorthy, Hance, & Darzi, 2006; Aggarwal, Grantcharov, & Darzi, 2007; Masters, Poolton, Abernethy, & Path, 2008b; Masters, Lo, Maxwell, & Patil, 2008a; Razavi et al., 2010). Over time the skill-parts are practised with increasing order of task complexity and reconstructed together until integrated and whole-task practice is achieved (van Merrienboer & Sweller, 2010; Spruit et al., 2014). Therefore, we assert that cognitive task analysis is an important contemporary approach to use when teaching complex skills.
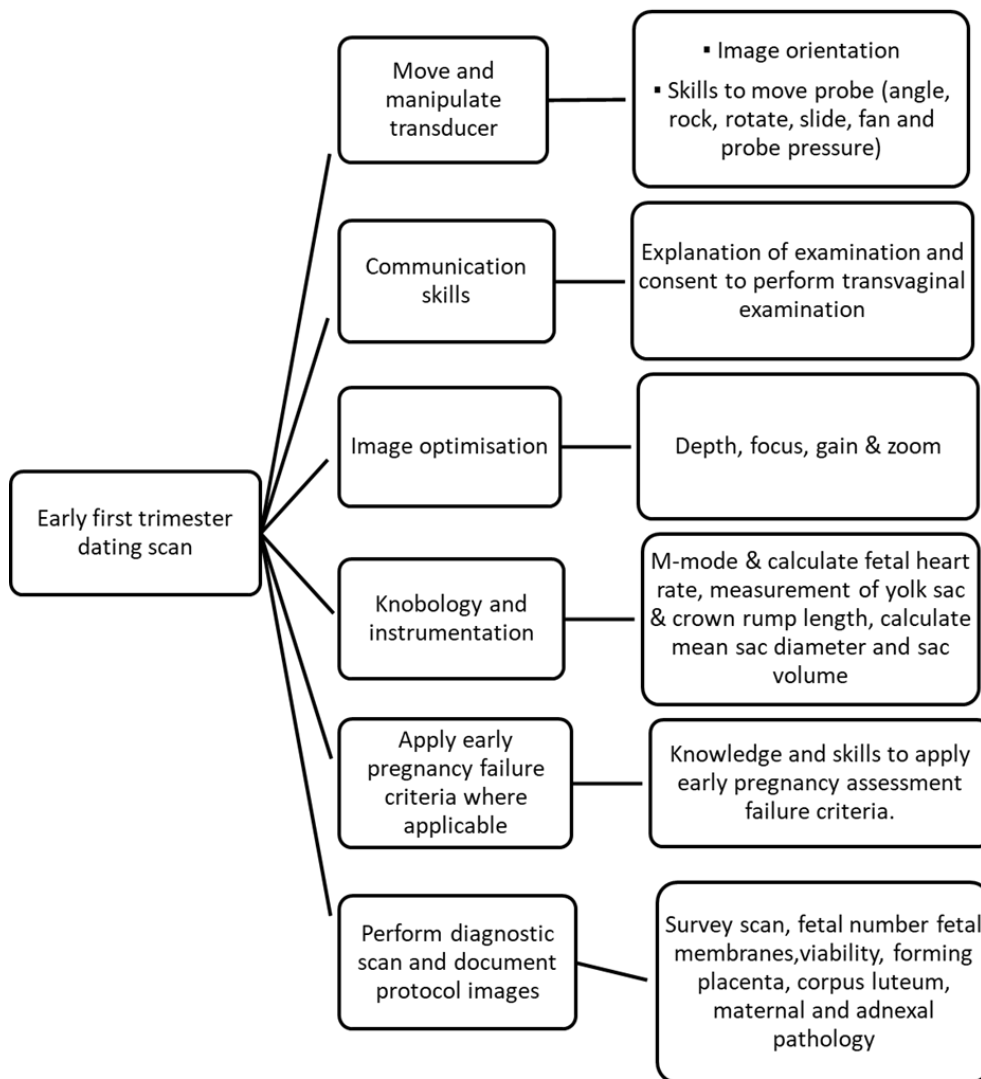
Figure 4.1: Skill task analysis to teach early first trimester dating ultrasound

4.5   Identifying Learner Skill Level and Learning Needs

Assessing the learner's prior knowledge and experience of a skill *before* teaching a complex clinical skill is an important instructional approach when preparing to teach because it avoids repetition and potential disengagement of the learner (Rose & Best, 2005; Dent & Harden, 2009; Spruit et al., 2014). Raman and Donnon (2008) suggest that adopting this practice benefits both the learner and the educator because it brings clarity to the teaching/learning start point for both parties. Furthermore, Foy and Evans (2009) assert that this practice enables the maximum use of skill-teaching time and avoids over- or under-estimating a learner's ability which can impact upon educational outcomes. Importantly, Faarvang and Ringstead (2006) point out that identifying learners who have been taught a skill incorrectly is another tangible benefit of ascertaining a learner's prior skill practice, knowledge, and experience. The use of open questions to elicit cognitive and task-based knowledge, as well as reviewing logbooks and asking the learner to

perform a simulated skill demonstration, are tools the educator may use to establish knowledge prior to skill teaching. We suggest that this is an important precept of contemporary skill-teaching model.

4.6   **Pre-skill Conceptualisation (Sensory Norms)**

This step occurs prior to the skill-teaching session and relies on the learner being taught the information and skill practice norms relevant to performing the task. The unique elements relevant to the skill are reviewed and described by the educator and, as an example include: skill protocols; diagnostic criteria; patient safety; sensory (visual, tactile and auditory) norms associated with executing the task; equipment handling, care, and safety; and anatomy, physiology, and pathophysiology linked to competent execution of the task. The instructional approach used by the educator to teach the theory linked to understanding and performing a complex skill is also important. Deconstructing the theory into manageable portions (cognitive task analysis) before the task is taught has two important benefits to the learner: this approach minimises the cognitive load required to process large volumes of core knowledge which are central to a learner being able to perform the task, and it avoids the skill steps and information elements being taught concurrently. Teaching a learner how to perform a task whilst overlaying the task with information on how to operate the equipment, for example, is detrimental to the learner. This is because the learner's attention is divided (Leppink & van den Heuvel, 2015) between performing the task while simultaneously processing the incoming verbal information provided by the educator, which results in overloading the working memory and cognitive overload. Leppink and Heuvel (2015) point out that teaching practices which divide a learner's attention should be avoided when teaching a skill.

The use of e-learning technologies is one teaching strategy which provides the relevant resources and information required to perform a manual task before learning the skill without overloading or overwhelming the learner (Cosyns, De Diego, Stefanidis, Galderisi, Ernande, Underwood, Bucciarelli-Ducci, Lancellotti, & Habib, 2015). A further advantage of using this technology is core knowledge and informatics are relevant to skill acquisition, and performance can be delivered synchronously or asynchronously via these multi-media technologies (Cosyns et al., 2015) to suit a learner's workplace commitments (Dent & Harden, 2009) and lifestyle.

4.7   Demonstration–Visualisation

Teaching the sub-part of a psychomotor skill should *always* commence with the educator performing a silent rehearsal of a predetermined number of task elements. Adopting this instructional technique enables the learner's visual neural tract to focus on the motor movements linked to the skill, without the brain processing additional sensory information, (Leppink & van den Heuvel, 2015) which occurs when the educator provides a narrated skill demonstration. Cosyns et al (2015) suggests that a silent video clip of a skill performance which portrays the motor movements, and what the skill should look like at the conclusion of each step, is a valuable use of e-learning technology to guide complex skill acquisition.

The five-step model by George and Doto specifies that the learner must see a complete skill rendition of the task as this importantly serves as a *"....model of* performance" or what the skill should look like (2001 p.577). Additionally, this standard is used by the learner *"to self-evaluate their own performanc*e" (George & Doto, 2001, p. 578). Furthermore, Cornford (1999) from a nursing perspective, suggests that the primary purpose of a real-time demonstration is to provide a mental model or schema of the skill. This exemplar demonstration serves as a visual standard of performance when learning skills across health disciplines (Milde, 1988; DesCoteaux & Leclere, 1995; Cornford, 1999; George & Doto, 2001; Raman & Donnon, 2008; Foy, 2009). Cornford (1999 p.267) asserts that the exemplar should be performed by an expert, and provide both the correct *skill sequence* and *timing*. Additionally, Milde (1988 p.420), again from the nursing literature, proposes that "*in order to diagnoses errors a learner must have a template or internalised standard of performance*". Error detection by the learner is important when performing a simple or complex skill and relies on knowing the expected or "normal" sensory norms linked to competent skill execution. We suggest, this is important in order to be able to identify when the skill does not 'look', 'feel', or 'sound right'. This traditional skill-teaching step has thus been further explained in the context of contemporary instructional practice.

4.8   Demonstration–Verbalisation

After performing a silent rendition of the skill steps, the educator repeats the skill demonstration while simultaneously providing *a brief* description of the task steps being performed (Hammond & Karthigasu, 2006; Abela, 2009). To be able to demonstrate and succinctly narrate a limited number of skill steps, the educator must, prior to the teaching session, identify the finite number of skills to be taught in the session (task analysis), sequence the task parts (where appropriate) from

simple to complex, and identify and limit narration to include only the key points. The models by Walker and Peyton (1998) and George and Doto (2001) recommend demonstrating the task while describing the skill steps. Additionally, George and Doto (2001 p.578) emphasise the need to "describe in detail each step in the process" as it is performed. However, Leppink and Heuval (2015), and Young et al (2014) assert that this instructional approach is deleterious to a learner when acquiring and learning a psychomotor skill for two reasons: 1) the learner's attention is divided between two sources of information (visual and auditory) entering the brain; and 2) the volume of cognitive information (a verbose narration) and the duration over which the information is delivered to the brain overwhelms working memory. This is because the duration and volume of data exceeds working memory capacity when the brain receives information from multiple neural tracts to process concurrently (Leppink & van den Heuvel, 2015). Providing a skill demonstration whilst briefly narrating the discrete task steps is an important instructional approach to counteract the impact of cognitive or information overload. Therefore, the demonstration-verbalisation teaching step (which includes limiting the number of elements taught in any one skill-teaching session) is an amalgamation of seminal and contemporary skill-teaching literature.

4.9   **Immediate Error Correction**

It is important the educator provide immediate error correction of incorrectly rehearsed or executed skills as they occur (Winstein, 1991; Winstein, Pohl, & Lewthwaite, 1994; DeBourgh, 2011). The purpose of error corrective feedback is to prevent a skill being practised, encrypted, and stored in long term memory incorrectly (Kleim, Hogg, VandenBerg, Cooper, Bruneau, & Remple, 2004; Kantak & Winstein, 2012). Recalling an incorrectly learned skill may result in patient harm (Winstein, 1991; Winstein et al., 1994; Kovacs, 1997; DeBourgh, 2011). Error corrective feedback is advocated and endorsed by authors in dentistry, surgical medicine, and nursing disciplines (George & Doto, 2001; Brovelli, Laksiri, Nazarian, Meunier, & Boussaoud, 2008; Masters et al., 2008a; Masters et al., 2008b; Foy, 2009; Roberts, Vignato, Moore, & Madden, 2009; DeBourgh, 2011).

4.10   **Limit Verbal Guidance and Coaching**

When teaching a psychomotor skill the communication between the educator and learner should be specifically limited to the skill-teaching steps required to learn the task (Winstein, 1991; Walsh et al., 2009). Importantly, this is not the time to be engaging in points of clarification with the

learner or providing verbal skill guidance or coaching. For highly tactile skills such as medical ultrasound, non-verbal feedback in the form of providing physical guidance may be useful to learn the (sometimes inexplicable) multiple fine and gross motor movements. Given that most ultrasound skills are open and complex and therefore difficult to learn (Scott, Thomas, Edwards, Jones, Swan, & Wessels, 2013; Nicholls et al., 2014; Cosyns et al., 2015), non-verbal guidance may be required to move and manipulate the ultrasound transducer. However, this guidance should occur with limited verbal dialogue to enhance the learning potential.

Verbal guidance and coaching from the educator is problematic and detrimental to a learners' skill acquisition for three reasons. First, it takes the learner's focus and attention away from recalling or executing the task (Winstein et al., 1994; Walsh et al., 2009; Kantak & Winstein, 2012). Important sensory and tactile information linked to the task are not learned because the learner is focussed on the extraneous verbal information provided by the educator, rather than focussing on executing the task (Kantak & Winstein, 2012). Second, overlaying a task with verbal guidance may potentially overload the limited and finite working memory, and divide attention while the learner attempts to process multiple domains of information concurrently (Young et al., 2014; Leppink & van den Heuvel, 2015). Third, and most importantly, the skill is learned inclusive of the coaching and guidance provided by the educator, so the student may become reliant upon the educator to complete the task. This phenomenon is known as the guidance hypothesis (Schmidt, 1975; Poole, 1991; Walsh et al., 2009; Schmidt & Lee, 2011; Kantak & Winstein, 2012). Therefore, during the skill acquisition phase, when a learner is either verbalising or executing skill steps, limit guidance and coaching to maximise the learner's skill acquisition potential and always immediately correct verbalised or skill execution errors, at the time they occur.

4.11 Verbalisation–Execution

The next step to teaching psychomotor skill acquisition involves the learner describing the individual tasks before the educator performs it. The action of describing the sequenced skill steps prior to executing the task components is referred to as 'verbalisation'. This teaching strategy is used by the George and Doto (2001) and Walker and Peyton models (1998) of teaching psychomotor skills. While Walker and Peyton (1998) do not explain the rationale for this teaching strategy, George and Doto (2001 p.577) state " If the learner is able to narrate correctly the steps of the skill before demonstrating there is a greater likelihood the learner will correctly perform the skill". However, neither author provides an explanation as to why this action assists cognition of a

psychomotor skill. Educators outside of the health field, Anderson (1997) and Gidley et al (2015), state that verbalisation or self-declarative instruction is an important cognitive strategy when acquiring and learning psychomotor skills. Additionally, Anderson (1997 p.31) points out that self-instruction provides an opportunity for the educator to "eavesdrop on the learner's thinking" which reveals the learner's knowledge of the skill steps, sequencing, and timing. This is an important step, in conjunction with immediate error correction, to encrypt an error-free motor map for each skill element. A contemporised psychomotor skill-teaching model must include verbalisation or self-declarative instruction as an instructional step when teaching task-based skills prior to skill performance.

4.12   **Verbalisation–Performance**

This step involves the learner describing the skill steps before performing the task. Verbalisation precedes the execution of the skill and this action focuses the learner's attention onto the skill elements and features. Verbalisation is helpful in learning a skill routine-expediting acquisition of motor sequences and psychomotor skill accuracy (Sun, Slusarz, & Terry, 2005; Gidley Larson & Suchy, 2015). Verbalisation is an, important aspect in task learning which assists in skill encoding, encryption, and recall (Cornford, 1999; Kray, Lucenet, & Blaye, 2010) which are considered more essential than rote learning a psychomotor skill (Gidley Larson & Suchy, 2015). When learning a task, verbalisation is an important teaching tenet, in conjunction with skill performance, to guide the cognitive acquisition of a skill and to create a schema for the skill in the motor cortex. A motor map or schema is required for each new skill being acquired and is a precursor to a skill being moved to long term memory and being able to be recalled when required.

The verbalisation-performance instructional approach is adopted in George and Doto's (2001) and Walker and Peyton's (1998) models to guide psychomotor skill acquisition, but they do not provide explanation as to where and why. George and Doto (2001 p.578) assert the educator should provide " ...feedback and coaching as needed". However, the contemporary literature presented in this paper identifies this practice is deleterious and an impediment to task acquisition by low-skilled learners, because it divides their attention (Walsh et al., 2009; Kantak & Winstein, 2012). Therefore, a contemporised psychomotor teaching model must include the verbalisation-performance instructional step while acknowledging the importance of providing immediate error correction and withholding any other verbal feedback or coaching.

4.13   Skill Practice

Learning a psychomotor skill and correctly encrypting in the motor cortex is reliant upon both skill practice opportunities and terminal feedback. Ericsson (1993) points out that skills are acquired through diligent practice. Importantly, Kleim et al (2004) and DeBourgh (2011) assert that the frequency and repetition with which a task is practised impacts on the encryption of motor maps, and therefore on skill retention, recall, adaptation and transfer of learning to other environments (simulation and bedside). A learned skill is capable of being adapted and modified to each clinical scenario (Schmidt, 1975; Wise & Willingham, 2009; Kantak & Winstein, 2012). Foy and Evans (2009) corroborate the need for multiple short practice opportunities when encrypting the motor map for a skill. DeBourgh (2011) and Kantak and Winstein (2012) argue that long and infrequent practice sessions may deleteriously affect skill encryption. Numerous practice sessions (less than 60 minutes in duration) and variable task sequence practice opportunities facilitate the process of skill encoding, consolidation and recall (Poole, 1991; DeBourgh, 2011; Kantak & Winstein, 2012; Spruit et al., 2014). Foy and Evans (2009) also assert that skill practise variation is important when learning psychomotor skills and this, we suggest, has implications when using low-fidelity simulation tools where practice conditions are relatively constant, to teach task-based skills. Therefore, skill practice is reliant upon multiple spaced, short duration, and variable task practice opportunities to promote skill acquisition and long-term retention by the learner.

4.14   Post-skill Execution Feedback

Motor skill acquisition is reliant upon task practice and feedback (Archer et al., 2015). Feedback refers to the unique information provided by the educator to the learner, on an observed skill performance (Schmidt & Lee, 2011; Ramani & Krackov, 2012) . The primary goal of feedback is to progress skill performance. Notwithstanding skill rehearsal and repetition, feedback is the single most influential teaching practice to promote motor learning. Psychomotor skill feedback may be intrinsic, derived from the learners' own sensory realm based on the mental model of the skill, or extrinsic and provided by the educator after observing the performance (Winstein, 1991; Poole, 1991; Walsh et al., 2009). Examples of extrinsic feedback include error correction, concurrent, and terminal feedback. Terminal feedback is provided at the conclusion of an observed skill performance (Poole, 1991; Winstein, 1991; Walsh et al., 2009) and provides information on the task performance and success (Ende, 1983; Salmoni, Schmidt, & Walter, 1984; Walsh et al., 2009; Dent & Harden, 2009). The timing and form of feedback are influential to a learner's mental cognition which guides future motor actions.

The Pendleton feedback model (Pendleton, Schofield, & Tate, 1984) is one tool to structure and sequence motor skill feedback, although the model was not specifically intended for this purpose. Salmoni, Schmidt & Walter (1984) point out that educator feedback should be withheld until the conclusion of the skill (Salmoni et al., 1984). This allows the learner to practise whilst focusing on the sensory, motor, and tactile skill elements without receiving a bombardment of verbal information (Salmoni et al., 1984; Schmidt & Lee, 2011). Significantly, terminal feedback influences the encryption of correct motor sequences or skill encoding during the acquisition phase (Kantak & Winstein, 2012). Terminal feedback which is based on motor skill actions is crucial to effect modification of motor behaviour and future practice performance (Salmoni et al., 1984; Poole, 1991). The quantity, timing, and type of feedback provided by the educator to the learner during performance of a motor skill is therefore important and may enhance or be deleterious to motor skill learning.

4.15   Conclusion

Modern health professionals, as a part of their clinical practice, are required to learn and perform a diverse range of complex psychomotor skills. Motor-learning theorists have long posited using a stepped instructional approach to guide skill acquisition. However, recent literature has identified, with regards to skill acquisition and retention, that there is limited evidence to suggest the widely accepted four step (Walker & Peyton, 1998) and five step (George & Doto, 2001) skill-teaching models, have application to teach a complex skill. Despite this, these archetypal tools continue to be used to teach simple and complex tasks.

Contemporary motor-learning literature points out that there are important teaching approaches which collectively guide and develop skill acquisition and retention by a learner. However, these steps have not made their way into the skill-teaching process. This article presents the instructional steps to teach complex psychomotor skills premised upon seminal and contemporary literature. We have highlighted eleven evidence-based skill-teaching approaches that are necessary to teach complex multi-part tasks to ensure they are learned, both recalled from long-term memory, and are resistant to error.

4.16 **Summary**

This chapter presented the instructional steps of teaching complex psychomotor skills, as premised upon seminal and contemporary literature. This synthesis makes an original contribution to the body of knowledge that relates to teaching a complex psychomotor skill. This review has outlined the necessity of the educator to undertake a process of cataloguing a psychomotor skill prior to teaching it. There are hypotheses, theorems, and principles that are distinct to this skill classification. Finally, an 11-step instructional model, which incorporates evidence-based skill-teaching approaches, has been proposed to teach complex multi-part tasks. Using this model to guide the teaching and the practice of complex skills maximises the potential for the skill to be acquired and learned without encryption error. This instructional model makes a novel contribution to knowledge through the fusion of contemporary motor-learning theoretical principles with the practical application of teaching a complex psychomotor skill in ultrasound.

In the next chapter, the pedagogical steps that are required to teach the communication skills that co-occur with the psychomotor skills performed in clinical practice are reviewed. In particular, the next chapter reviews the steps required to teach the verbal skills that accompany the performance of scanning skills or other clinical skills. A model to teach the concomitant communication skills is presented. Importantly, it will be argued that the learner cannot learn both skill sets at the same time, because to do so will exceed the finite and limited capacity of the learner's working memory.

5 TEACHING THE CONCOMITANT COMMUNICATION SKILLS THAT ACCOMPANY THE EXECUTION OF A PSYCHOMOTOR SKILL

Most ultrasound examinations are performed on a conscious patient and the skill therefore cannot be performed devoid of communication. Performing an ultrasound examination involves the sonographer communicating with the patient before, during, and after the scan. Communication skills, as well as psychomotor skills, need to be first taught and then learned. A large body of literature exists which outlines the pedagogical approaches, theories, and principles to teach communication skills to health professionals and other professions. These principles and pedagogical approaches have focussed on teaching and learning the skills to be able to verbally converse with the patient and to perform focussed tasks, such as getting the patient's medical history. However, there is very little health professional literature which has targeted the teaching and learning of the co-occurring communication skills that are needed while a clinical skill, or ultrasound examination, is performed on a conscious patient. This skill set is essential for all those health professionals who strive to deliver patient-centred care. Consequently, there was a gap in the literature which examined the theory, knowledge, and scholarship related to this topic.

This body of work would have been incomplete without researching the pedagogical approaches needed to teach the supporting, but essential, verbal communication skills that are required throughout the execution of a clinical task. The following peer-reviewed published paper outlines the theory and instructional approaches for an educator to teach these skills. A seven-step model is proposed to teach the co-occurring verbal communication skills that accompany a clinical skill. Importantly, the paper suggests that the psychomotor skill should be learned before the accompanying communication skills.

The following text was published in the peer-reviewed article listed below.

A model to teach concomitant patient communication during psychomotor skill development. Nicholls, D., Sweet, L., Muller, A., & Hyett, J. *Nurse Education Today* 2018; 60:121-126. *Citations (2)*

5.1 Abstract

Many health professionals use psychomotor or task-based skills in clinical practice that require concomitant communication with a conscious patient. Verbally engaging with the patient requires highly developed verbal communication skills, enabling the delivery of patient-centred care.

Historically, priority has been given to learning the psychomotor skills essential to clinical practice. However, there has been a shift towards also ensuring competent communication with the patient during skill performance. While there is literature outlining the steps to teach and learn verbal communication skills, little is known about the most appropriate instructional approach to teach how to verbally engage with the patient when also learning to perform a task. A literature review was performed, and it identified that there was no model or proven approach which could be used to integrate the learning of both psychomotor and communication skills. This paper reviews the steps to teach a communication skill and provides a suggested model to guide the acquisition and development of the concomitant -communication skills required with a patient at the time a psychomotor skill is performed.

5.2   Introduction

In clinical practice, health professionals perform psychomotor skills (also termed procedural, clinical or technical skills) that are unique to their discipline. Most clinical skills, when performed on a conscious patient, require simultaneous communication with the patient, using a set of vocabulary distinct to the discipline (Kneebone et al., 2002; Nestel, Kneebone, & Kidd, 2003b; Nestel, Kidd, & Kneebone, 2003a; Pugh, Hamstra, Wood, Humphrey-Murto, Touchie, Yudkowsky, & Bordage, 2015). Historically, priority has been given to learning the procedural task, i.e. accurate performance with correct sequencing and timing, before learning the inextricably linked and co-occurring communications skills. The decision by the educator to preference the teaching of the task before the linked communication skills has unintended learning benefits. This is because the learner derives, through practise, the experience of the sensory and tactile responses that are associated with performing the task steps. The learners need this knowledge of the sensory manifestations associated with performing a task before they are able to explain to the patient what they will feel, hear, see, smell, and importantly, at what time these will be experienced. However, having a knowledge of these sensory outcomes does not necessarily equip a learner with the vocabulary and the communication skills to be able to describe them to the patient.

Notably, little attention has been paid to how the learner gains this knowledge of sensory outcomes or the concomitant verbal communication skills that accompany a clinical task. In an era where the delivery of patient-centred care is now a focal point of health professional education it is vital that there is equality of both skills. That is, the skill of effective communication during task performance as well as being a competent practitioner. At the time of task performance, being an

effective communicator is one facet of providing patient-centred care (Nestel & Kneebone, 2010; Cushing, 2015). Examples include: verbally engaging with the patient; disclosing and conveying relevant information related to task execution (Bearman et al., 2011); and using an engaging and empathetic style at the time a procedure is being performed (Noble, Kubacki, Martin, & Lloyd, 2007; Cushing, 2015; Deveugele, 2015). For each new task performed, both the procedural and communication skills must first be taught, then acquired, and finally learned over time (Burton & Dimbleby, 1990; Aspegren, 1999; Nicholls, Sweet, Muller, & Hyett, 2016a). We suggest that the task should be learned in advance of the co-occurring communication skills. This approach enables the learner to first gain a knowledge of the real-time sensory and tactile norms linked to task practice, prior to practising the procedure. With advancing task proficiency, and the freeing up of working memory, the learner is more capable of paying attention to the educator's vocabulary and communication style which is used to describe to the patient the task steps and the expected outcomes as they occur.

More than a decade ago, a limited number of authors (Yoshida, Milgrom, & Coldwell, 2002; Kneebone et al., 2002; Nestel et al., 2003a; Nestel et al., 2003b) pointed out that it was a rudimentary requirement of all health professionals to be able to communicate with the patient at the time a task was being performed. At this time, some educators believed that the skills to become an effective communicator for clinical task performance were taught during the undergraduate curriculum (Kneebone et al., 2002). However, Yoshida, Milgrom, and Coldwell (2002 p.1281) found that the educational practices used to teach communication skills to dental students attending American medical colleges were unstructured and loosely evaluated. Therefore, there were concerns that the students were not being equipped with effective communication skills for task performance. Similarly, Nestel et al. (2003b) reported that nurses did not receive adequate communication training during their undergraduate education. Subsequently, health disciplines have made broad sweeping changes to their curricula in a quest to enhance health professional students' communication skills and equip them with the knowledge, skills, and attitudes to be able to deliver patient-centred care (Deveugele, 2015; Cushing, 2015). Paradoxically, there remains a limited literature outlining the pedagogical approach to teach and learn the concomitant psychomotor and communication skills for a given procedural, clinical, or technical task. Importantly, and to our knowledge, there is no model or method to specifically guide the acquisition of the communication skills linked to task performance. Therefore, it is unclear how these skills are taught and learned in clinical practice. A

decade or more has passed since this body of work and little is known of the pedagogical techniques or best practice approaches to teach the communication skills that are inextricably linked to psychomotor skill acquisition and practice.

The purposes of this paper are threefold: 1) to evaluate the theoretical and instructional approaches currently used to teach basic communication skills; 2) to review the current skill-teaching models and determine whether they make provision to teach the simultaneous communication skills related to a task on a conscious patient; and as a result of these findings 3) to suggest an instructional approach for educators to use to teach the communication skills required for competent task practice.

5.2.1 A review of the literature

A literature search was undertaken using the following data bases: Google Scholar, ProQuest, ERIC, CINAHL, and Medline, between 1990-2016. The keywords and phrases used for the literature search included: 'teaching', 'simulation', 'role-play', 'technical skills', 'procedural skills', 'clinical skills', 'psychomotor skills', 'non-technical skills', 'communication skills', 'teaching method', 'teaching model', 'education', 'medical', 'nursing', 'dentistry', 'allied health', 'postgraduate', and 'undergraduate'. Additionally, the reference lists of the retrieved papers were checked. Those references which included 'psychomotor skill', 'procedural skill', 'communication' or 'non-technical skills' in their title or as a keyword were also included in the review. There were 103 publications retrieved. Identified references were excluded when: 1) the main purpose of the article was to report deficiencies in communication skills within a profession and/or to suggest these skills be included in the curriculum; 2) the central outcome related to assessment; 3) the non-technical skills described talking to fellow peers and colleagues and not patients; and 4) duplicate papers were identified. Following the exclusion process, 30 articles remained, and they were thematically synthesised to meet the paper's aims. Synthesis of the retrieved literature identified that the teaching of communication skills to health professionals requires a stepped and sequenced pedagogical approach (see Table 5.1), and often delivered using role play and the receipt of end-of-task feedback. In contrast, there was a paucity of literature detailing the instructional approaches to be used by educators when teaching the co-occurring communication skills that are required when a clinical or procedural skill is performed.

5.2.2 The communication steps required to complete a clinical skill

Effective patient communication relies on the learner being informed of the distinct points in time when communication is needed during the performance of a clinical skill on a patient. Importantly, Bearman et al. (2011) and Nestel et al. (2003a) point out that performing a procedural skill on a conscious patient may require up to four discrete stages of verbal communication. The first step is to explain what the procedure entails and obtain informed consent. Following this, the clinician explains what they are doing, during the procedure. Thirdly, there may be error disclosure (if necessary). Finally, communication of any post-procedure care is needed (Bearman et al., 2011). To deliver this entire package of information to the patient, the clinician requires knowledge of the task, standards of practice, as well as effective communication skills. Furthermore, we suggest that the language and vocabulary used to inform the patient is often discipline-specific. Therefore, the educator should attend to teaching the learner a glossary of words to accompany and simply explain the executed task, without using jargon. Adopting an inclusive approach with the patient enables them to understand what is about to occur. Furthermore, the open forum of communication encourages a rapport to be established, which fosters a pathway of two-way communication between clinician and patient.

Execution of skilful and effective communication, at the time of task performance, relies on the practitioner using both verbal and non-verbal elements (Teutsch, 2003; Lucander, Knutsson, Salé, & Jönsson, 2012). The non-verbal component is comprised of body language, voice tone, and mannerisms such as making eye contact (Teutsch, 2003). The focus of this paper is on acquiring and developing *verbal* dialogue skills which are used *at the time* a clinical skill is performed.

5.2.3 The benefits of being an effective communicator at the time of task execution

The real-time verbal interaction with a conscious patient, as a clinical skill is performed, is an example of a complex skill and involves the health professional being able to convey to the patient what the task involves as it is performed. The antecedent benefits of becoming an effective communicator are however only realised when learners have acquired the relevant communication principles and know how to use them effectively. At the time of task execution, this often involves explaining the task sequencing (where required), outlining how the patient may be required to assist during the task (such as holding their breath or swallowing), highlighting the sensory repercussions they may feel as specific steps are performed ("needle prick and then a sting now" or "you may hear a crunching noise now as the speculum is removed"), and checking on their wellbeing throughout the procedure. The provision of a commentary by the clinician

provides a platform to establish a professional relationship with the patient, as well as building trust and co-operative investment (Maatouk-Burmann, Ringel, Spang, Weiss, Moltner, Riemann, Langewitz, Schultz, & Junger, 2016). The latter is essential for those procedures that require patient participation to complete the task. For example, during a CT-guided percutaneous needle biopsy of a lung mass the patient is advised not to cough, wriggle or change their breathing pattern (Wu, Maher, & Shepard, 2011).

Being an effective communicator involves the clinician being cognisant of a patient's cultural aspects (Jayawardene & LaDuca, 2014), and being able to understand the patient's tone of voice, behaviour, and style of verbal communication (Nestel et al., 2003a). Additionally, it is important to have the nuanced communication skills to engage with patients when they are angry, in pain, or asking difficult questions. This skill becomes particularly challenging to execute for all practitioners when there is a language barrier (Catana, 2014), or if the patient is intellectually disabled, stressed, or anxious (Kai, 2005).

There are numerous benefits derived from effective communication with patients. These include improved patient satisfaction and compliance (Teutsch, 2003), efficient assessment of patient history, and a reduction in patient distress and anxiety (Yoshida et al., 2002; Jayawardene & LaDuca, 2014). Importantly, the outcomes of being an effective communicator include reduced patient complaints (Maguire & Pitceathly, 2002; Deveugele, Derese, De Maesschalck, Willems, Van Driel, & De Maeseneer, 2005) and fewer post-operative complications. In contrast, poor communication may result in negative patient responses and outcomes. These may develop when the clinician communicates unnecessary and superfluous information that causes patient anxiety (Jayawardene & LaDuca, 2014) or alternatively they may flounder, not knowing what to say to the patient (Noble et al., 2007), so providing insufficient information. Consequently, the patient experiences a loss of confidence in the clinician and is reluctant to accede to instructions provided by the health professional (Maguire & Pitceathly, 2002).

5.2.4 The limitations of working memory: overload from teaching communication skills with task performance

Silverman and Wood (2004) suggest that communication skills are more complicated, therefore more difficult to teach and learn, than the majority of procedural tasks. This is an important consideration because multi-part and complex procedural skills are difficult to teach and learn (Nicholls et al., 2016a). Therefore, when the educator attempts to simultaneously teach the co-occurring communication skills linked to task practise, and the skill is multipart, the educational

outcomes become tenuous. In this teaching setting, there is real potential for the educator to place the learner into cognitive overload, when the task steps and communication skills are taught concomitantly. As this practice overloads the finite capacity of working memory, when the tasks are new and unfamiliar to the learner. This is because learning a new and multi-stepped task involves a large amount of data being placed on the 'clip board' of the central processing unit of the brain (or working memory) which requires processing. When the data is both novel and large in volume the brain becomes 'bottlenecked' and then overloaded, due to the limited processing capacity of working memory. The constraints of working memory are referred to in cognitive load theory, and they have noteworthy teaching and learning outcomes (van Merrienboer & Sweller, 2010; Young et al., 2014; Leppink & van den Heuvel, 2015; Spruit et al., 2015). In a clinical practice setting, overloading working memory results in protracted learning outcomes, erred student performances and practice renditions (van Merrienboer & Sweller, 2010; Young et al., 2014; Leppink & van den Heuvel, 2015), as well as attention paid to performing one task at the exclusion of another (Spruit et al., 2014). Therefore, when the task being taught is both complex (multipart) and difficult, the content should be delivered in sequential, logical, and small chunks using an uncomplicated teaching format (Leppink & van den Heuvel, 2015). Hence, psychomotor and communication skills linked to task practice should not be taught at the same time, but rather as distinct skill sets taught and learned separately, with a transition to integrated whole-task performance.

Two studies were identified which exposed the educational outcomes of learners striving to learn to communicate with a conscious patient at the time of task execution. Kneebone et al. (2002) explored the performance of second and third year undergraduate medical students who were tasked with communicating with a simulated patient whilst performing a procedural skill. One of their objectives was to investigate whether the co-occurring communication and procedural skills could be taught and practised concurrently, thus avoiding disassociation of two inextricably linked skills (when learned separately). The clinical task being undertaken was either urinary catheterisation or wound closure. For each scenario, a simulated patient with an attached latex phantom was used to create an authentic practicum. The participants had received prior clinical training (during a six-week clinical placement) to both perform the procedure and communicate effectively. However, the study provided no details of the method used to equip the participants with the necessary skills or vocabulary to communicate with the patient nor how to integrate the two activities. The authors stated that "..all participating students had received communication

skills teaching, prior to entering the study" (Kneebone et al., 2002 p.629). A major finding of the study was that the participants could either execute the procedure or communicate with the patient, but not perform both activities together (Kneebone et al., 2002 p.633). A further outcome of the study was that none of the participants completed the tasks in the allotted time of ten minutes. These findings suggest that the integration of communication and psychomotor skills, for this cohort of novice practitioners, was cognitively demanding. This inability to complete an integrated task in a pre-determined time frame suggests that the learner's cognitive processes became overloaded. Furthermore, the results highlight that these students were incapable of attention splitting which has also been recognised by Spruit et al. (2014). Thus, most of the learners elected to complete only one of the two tasks.

In the second study, Nestel et al. (2003b) taught a multi-part procedural task (ellipse excision of a skin lesion and wound closure) to a small group of eight experienced nurses. The focus of the training was on the nurses' procedural skills and not specifically the communication abilities that accompanied the task performance. In particular, the nurses had received neither prior communication skills training or specific verbal training to accompany the tasks being performed (Nestel et al., 2003b p.293). They found that despite the nurses being proficient practitioners in their usual context, they suffered anxiety when the new tasks were performed together with communication. The results of this study raise some noteworthy considerations. First, the opportunity to practice skills using a structured teaching and feedback method was invaluable. However, when two complex tasks were executed simultaneously, the participants made unconscious technical mistakes, exhibited skill regression below their pre-course level, and experienced anxiety (Nestel et al., 2003b). This suggests that the cognitive demands of performing two complex tasks together placed an excess burden on their working memory and resulted in cognitive overload. This limited evidence suggests that it is important for the student to learn procedural skills in context to the concomitant communication skills linked to task practice. However, the evidence also suggests these skills should not be taught concurrently, because doing this, places both inexperienced and experienced clinicians into cognitive overload.

5.2.5   An implied skills-teaching curriculum

Currently, psychomotor skills are taught and acquired in simulation-based or patient-based learning environments using a range of skill-teaching models (for examples see Walker & Peyton, 1998; George & Doto, 2001; Hammond & Karthigasu, 2006; Raman & Donnon, 2008). Some of these models include an instructional routine which requires the learner to verbalise the skill

step(s) before performing the task (for example Walker & Peyton, 1998; George & Doto, 2001). The purpose of the instructional routine is not to develop the learner's communication skills which are linked to task performance, but to ensure the student knows the requisite sequencing, timing, and motor actions to perform the procedure before executing them. However, when the patient is conscious, most clinical skills are not performed in a vacuum of silence. Yet there are no educational frameworks, that we could identify, which outline an approach to teach the concomitant communication skills. This suggests that the skill is taught and learned on-the-job as part of an implied skill-teaching curriculum. Nevertheless, there are scattered publications on the methods and approaches used to teach the verbal communication skills required by health professionals. The review of the articles will now be presented, identifying seven steps that are needed to teach communication skills in health education.

5.2.6 The theoretical principles to teaching communication skills

The review of the retrieved seminal and contemporary skills teaching literature, as presented above, identified seven instructional steps to effectively teach communication skills. Deveugele (2015 p.1288) points out that communication skills should be intentionally taught, using a logical and chronological approach. Therefore, these steps (along with the rationale and strategies for each stage of the teaching and learning process) are shown in 5.1. Teaching a learner how to become an effective communicator can be deconstructed into four main steps: 1) pre-skill conceptualisation; 2) teaching the theory and principles to effectively communicate at the time a procedural skill is performed; 3) role modelling the standard of performance, and 4) acquiring and learning the communication skills linked to task practice - from role-plays to on-the-job practice and the provision of feedback.

Table 5.1: The pedagogical steps to teach verbal communication skills for clinical skills

Steps to teach a communication skill	Educator strategies and rationale
1) **Identify the verbal script and skills to be taught**	List the skills, knowledge and vocabulary required by the learner to perform the task. Break the skill down into sections to avoid the effects of cognitive overload and to identify teachable portions (Sullivan et al., 2007; Jabbour et al., 2011; Leppink & van den Heuvel, 2015).
2) **Perform a needs assessment of the learner**	Establish the communication skill level of the learner. Assists correct assignment of learner activities to their ability. Avoids learner disconnection or overloading them (Bearman et al., 2011; Cushing, 2015).
3) **Teach theoretical knowledge and principles**	Identify the key words or vocabulary that are linked to the clinical experience and teach/make explicit to the learner. Provide an overview of the theory and principles required to be an effective communicator (Maguire & Pitceathly, 2002; Heaven, Clegg, & Maguire, 2006).
4) **Role-model the standard of performance**	Real-time demonstration of a standard of performance for the skill (learners must first observe the behaviour before being able to replicate the standard) (Anderson & Sharpe, 1991; Cushing, 2015).
5) **Role-play with and without simulated patients**	Provide a safe and interactive learning opportunity. Participants practice and refine: word selection, dialogue, delivery, timing, and new behaviours (Deveugele et al., 2005; Maatouk-Burmann et al., 2016). No requirement to simultaneously pay attention to the clinical needs of the patient (Kneebone, 2003; Kneebone et al., 2007). Simulated patients can be used to further develop the participant's talking, listening and situational awareness skills (Yule, Flin, Maran, Youngson, Mitchell, Rowley, & Paterson-Brown, 2008). Simulated patients are costly (Lane & Rollnick, 2007); therefore, peers and colleagues may assist with role-plays.
6) **Skill practice**	Provide multiple practice opportunities. Participants acquire, perform, and refine new behaviours and language skills. Skill transfer from the simulated environment to the clinical setting is contingent on guided educator supervision (Heaven et al., 2006; Lane & Rollnick, 2007)
7) **Feedback using a video or audio tape of skill practice, or from other agents**	Provide the learner with an opportunity to compare their own observed practice with the model of expected performance. Consider analysis of word selection, voice tone, and the speed at which the learner delivers their words. Feedback when using role-plays should follow these principles "learner first, positive first, constructive alternative". Procure feedback from the simulated patient (when beneficial to the learning experience) (Bylund, Brown, di Ciccone, Levin, Gueguen, Hill, & Kissane, 2008 p. 433). Objective evaluation, facilitated by the educator, is an important tenet of skill practice and feedback because self-reflective practice alone can be unreliable (Yule et al., 2008).

5.2.6.1 *Pre-skill conceptualisation*

Step One in the educational process is to identify the communication script and skills to be taught. The selected skill should then be broken down into the knowledge, task, and professional practice attributes related to its execution and into teachable portions – also termed cognitive task analysis (Sullivan et al., 2007; Jabbour et al., 2011). This is an important step to avoid overloading the learner's working memory during the initial stages of knowledge and skill acquisition.

Step Two is to undertake a needs assessment for the learner. Evaluating the student's current communication skill level and ability is necessary (Bearman et al., 2011; Cushing, 2015) to ensure the selected teaching and learning activities are aligned with the capabilities of the participant. This instructional step is essential to avoid learner disengagement.

5.2.6.2 *Teaching the theory and principles of effective communication*

Step Three involves teaching of the theoretical principles of verbal communication using pedagogical techniques suited to the learning context (Maguire & Pitceathly, 2002; Heaven et al., 2006; Bylund et al., 2008). It is important for the learner to understand and know the theoretical principles that are required to become an effective communicator, and this can be achieved through a range of pedagogical approaches. The delivery of theoretical principles is then followed with teaching the formal knowledge to perform the verbal communication, and the linking of the communication skills required for task execution.

5.2.6.3 *Role modelling the standard of performance*

In Step Four, the communication skill is performed by an expert using a live or video exemplar of performance to role-model the standard of performance. It is crucial that the behaviours and monologue for the task are correctly depicted and meet professional practice standards (Deveugele, 2015). The visual and auditory exemplar serves as a standard of performance for the learner (Anderson & Sharpe, 1991; Cushing, 2015).

5.2.6.4 *Acquiring and learning the communication skills linked to task practice*

The next three steps are inter-connected. There is consensus among researchers that communication skills are acquired and learned *only* through active and experiential learning (Maguire & Pitceathly, 2002; Bylund et al., 2008; Deveugele, 2015; Maatouk-Burmann et al., 2016), and the provision of feedback is instrumental to develop and reinforce correct skill acquisition (Berkhof, van Rijssen, Schellart, Anema, & van der Beek, 2011). Therefore, Step Five is to provide the learner with facilitated *skill practice using role-play* (with and/or without simulated

patients and inclusive of feedback), followed by Step Six, which is to transition to supported practice in the clinical setting. It is essential that these encounters are assisted by accomplished and trained educators in order to be able to effectively facilitate the student's task advancement from role-play to workplace practice (Heaven et al., 2006; Bylund et al., 2008). Practice opportunities allow the learner to scaffold their knowledge from 'knowing' to 'showing how' (Cushing, 2015), and it is through role-play that skills can be safely rehearsed, remodelled, and refined (Berkhof et al., 2011). Conscientious practice is required to acquire and then reinforce new knowledge and behaviours (Cushing, 2015). Step Seven, the final aspect, is to provide *feedback*, and wherever possible by using a recording of the learners' own performance for both self-assessment and educator feedback. Following the practice episode, the educator provides guided reflection, where the learner reviews and listens to an audio or video recording of their practice performance, and the educator supports them to explore what they did well and what could be improved at future attempts (Bylund et al., 2008). Additionally, trained simulated patients are a valuable resource to provide feedback to the learner on their clinical practice behaviours and attitudes (Maguire & Pitceathly, 2002). This feedback can then be used to refocus the learner's goals for the next encounter and foster the development of their self-assessment skills. With ongoing practice and facilitated reflection, skill acquisition can be scaffolded from initially using role-plays, to then performing the skill on a simulated patient (Pugh et al., 2015), and finally in the workplace. Teaching a communication skill culminates with the educator providing objective feedback on whole task performance. This is instrumental in effecting and galvanising the required changes in the learner's behaviour and attitude to become an effective communicator, as well as supporting skill transfer into the clinical setting (Heaven et al., 2006; Bylund et al., 2008; Berkhof et al., 2011).

To avoid the effects of cognitive overload when learning two contrasting and multi-part skills, the procedural and communication skills should be taught and learnt separately, and then combined. For clarity of presentation, the model to teach communication skills in Table 5.1, omits the important relationship between teaching the procedural task and the concomitant communication skill. We suggest that the psychomotor task should be taught and learnt *before* the communication skills linked to the procedure. This is because the learner must first have a solid understanding of the clinical skill and they must know the likely sensory elements that will be experienced by the patient before they are able to describe the chronology and timing of the task steps (and the likely sensory repercussions the patient may feel or hear).

5.3 Conclusion

There is an acknowledged need that health professionals should be able to effectively communicate with a patient at the time a procedural skill is performed. This paper synthesises the literature on the teaching and learning approaches required by the educator to develop the basic communication skills concomitant with clinical skill performance. A seven-step model to teach concomitant communication skills has been presented. We suggest that the co-occurring clinical skill is acquired and performed before teaching the related communication skills in order to minimise the effects of cognitive overload. To our knowledge this is the first time an explicit pedagogical approach has been posited to teach the concomitant communication skills that are linked to performing a procedural task. This contemporary synthesis of literature makes an original contribution to the knowledge of the instructional steps that are needed to teach the communication skills that accompany performing a psychomotor skill.

5.4 Summary

This chapter presented the theory and instructional steps that are required to teach the communication skills required during the execution of a clinical skill, or performing an ultrasound examination, on conscious patient. This synthesis makes an original contribution to the body of knowledge that relates to teaching the co-occurring communication skills that accompany and support the execution of a psychomotor skill. This review argues that the acquisition of the psychomotor skills and the communication skills which accompany the task are both examples of a complex skill. To learn both skills concurrently, due to the large volume and density of the information being taught and processed, would result in the learner's working memory becoming overloaded. Therefore, it is suggested that both skills are not taught concurrently. Rather, the psychomotor skill should be first taught, followed by the teaching of communication skills. To able to communicate effectively with an awake patient, the learner first needs to know the steps to perform the clinical skill, when and what information needs to be provided to the patient, at what time is the patient's assistance required to perform the task, the sensory outcomes related to performing the task, and the set of vocabulary to use. Once this knowledge is acquired, and they can perform the skill, and space is freed up in the working memory to attend to other tasks, for example communicating spontaneously with the patient. Until this point in time is reached, the sonographer educator is required to communicate with the patient. With ongoing skill practice, the motor program for the psychomotor skill becomes developed and then the learner gradually begins to convey to the patient the essential information to accompany the task.

A seven-step instructional model, which incorporates evidence-based skill-teaching approaches, has been proposed to teach the communication skills that accompany the execution of a clinical skill. This instructional model makes a novel contribution to knowledge through the fusion of the theories, principles, and pedagogical approaches required by an educator to be able to practically teach learners the communication skills needed during the execution of a psychomotor skill.

The following chapter presents a scoping review of the professional literature related to teaching and learning psychomotor scanning skills by the sonography profession globally, as well as other professions who use ultrasound to support their clinical practice roles. It describes the process used to undertake a scoping literature review and the outcome of the search results. The results of the literature review are examined to establish whether the research question has previously been researched and whether there is literature which outlines an instructional approach for teaching psychomotor skills to sonographers or other professions who use ultrasound imaging.

6   LITERATURE REVIEW

This chapter synthesises and discusses the outcomes from the literature review undertaken to glean how sonographers and other users teach the scanning (or psychomotor), skills required to perform an ultrasound. The scoping literature review was undertaken over a seven-year period and at the conclusion of this timeframe there remains, globally, a significant gap in the knowledge about how psychomotor scanning skills are taught. The initial review conducted at the beginning of this research project revealed a tangible lack of information about this topic. Across the seven-year period, the sonography profession began to research and describe the teaching approaches that were used by sonographer educators to teach psychomotor scanning skills, and this has been progressively added to the literature review for the final presentation of this dissertation. Following the initial review, the scope of the literature review was further widened to include those disciplines who also use ultrasound to assist their clinical practice roles, but revealed very few additional insights and knowledge. This confirmed that there was, and still remains, very little published information about this research topic.

6.1   Introduction

At the beginning of this research project, in 2012, there was very little literature which described, researched, or reported on the instructional approaches that sonographers use to teach psychomotor scanning skills. Moving forward to 2019, little has changed and there remains almost no empirical evidence about the pedagogical approaches that sonographers or other cohorts use to teach the psychomotor scanning skills needed for clinical practice. This lack of data and knowledge has both monopolised and constrained our limited understanding of the current instructional approaches that are used by sonographers. Therefore, a raft of questions remain unanswered. For example, are there teaching practices unique to the profession and why are they being used? Are there artisan or specific instrumental approaches that are used to teach specialist imaging groups, such as cardiac sonographers, and what is the rationale for using such teaching approaches? By modifying the currently used skill-teaching approaches, what teaching, and learning efficiencies could be realised? What are the similarities to, and disparities of, the current teaching methods compared to the suggested pedagogical approaches outlined in the skill-teaching and motor-learning literature? Finally, what are the educational barriers – real or perceived – to using a given pedagogical approach to teaching the psychomotor scanning skills required for clinical practice? Psychomotor scanning skills are just one component required to

perform an ultrasound examination safely. Nevertheless, these skills form the cornerstone of each examination. They involve an operator performing disparate skills, by each upper limb, either simultaneously or at differing times. Both skill sets are essential for the examination to be performed safely and accurately. The teaching and learning of these skills are antecedent to being able to demonstrate, assess, and document anatomical structures using grey scale imaging, motion mode, or pulsed-wave Doppler ultrasound. To explore the emergent body of knowledge, a literature review was undertaken, and frequently updated, to identify and map the articles which outlined the teaching or instructional approaches that sonographers use to teach the psychomotor scanning skills required for clinical practice. The initial review was limited to the profession of sonography. Due to the scarcity of literature found, the review was then expanded to include other professions who use and teach ultrasound imaging.

This chapter will provide the timeline of the literature review, the methods used to search and analyse the grey and published literature, and then a summary of the instructional approaches used to teach psychomotor scanning skills by operators across the globe.

6.2 Literature Review

6.2.1 Outlining the chronology and timeline of the literature review

A literature search was undertaken which included an extensive database search, a hand-search of professional journals, and a review of content of Australian professional and governance websites to identify grey literature related to the research topic. The initial search was conducted in September 2012 and at first was limited to the profession of sonography globally. At this time, no Australian ultrasound journals were indexed in databases such as Medline. Two papers were initially retrieved on the research topic (Sonaggera, 2004; Brown et al., 2011), and an additional paper was published at the end of that year (Thoirs & Coffee, 2012). The limited information on the research topic has meant that mapping the information has been difficult and has consequently involved identifying literature through snowballing and hand-searching the reference lists of target papers. Additionally, key textbooks have also been used to provide further information on areas related to the research topic, because foundation knowledge was not in the peer-reviewed literature retrieved from the database searches.

The presentation of this literature review is marshalled into two time points: an initial review performed at the beginning of the research project, followed by a progressive scoping review which includes publications and documents published from 2013 to 2019. At the initial review,

there were few publications describing the pedagogical approaches that sonographers used to teach psychomotor scanning skills. Consequently, all retrieved publications prior to 2013 were included in the initial review. No articles were excluded. The lack of publications and knowledge on the research subject was the catalyst warranting the commencement of the research project. Since 2014, there has been a slow increase in the number of publications related to the educational approaches used to teach psychomotor scanning skills, although very little literature was written by authors from the sonography profession. In contrast, other professional groups who have been using ultrasound imaging in niche areas – such as anaesthesiology, midwifery, cardiology, radiology, emergency medicine, and university faculties that have included ultrasound into their undergraduate medical education curriculum – have described and reported on their results which relate to teaching and learning ultrasound in these contexts. Therefore, the search terms were expanded in the final scoping review to include other professions and undergraduate medical education. This strategy was used to explore whether these cohorts had discipline-specific knowledge and data about the instructional steps and pedagogical approaches that are used to teach psychomotor scanning skills. The literature review concluded at the end of August 2019, as this was the time point that the final draft of the thesis was commenced.

6.2.2   The methods used to identify the relevant literature

A scoping review methodology was chosen to explore the literature and better understand the research topic. Levac, Colquhoun, and O'Brien (2010) provide a six-step framework to guide the retrieval and analysis of the literature related to the research topic. The framework was followed to ensure a robust, credible, and reliable analysis of the literature was undertaken. Using the review methodology developed by Levac et al. (2010), the six stages were as follows.

6.2.2.1   *Stage one: Identify the research question which will guide the scoping review*

The question used to scope the literature for the review differed from the primary research question. Two modifications were made. The phrase "In Australia" was omitted and the term "or educators" was added. These modifications were made to ensure that the scope of the question was broad enough to collect the relevant literature while making sure that the concept and population were clearly identified (Levac et al., 2010). The question used for this scoping review was: "What are the instructional approaches used by sonographers or educators to teach the scanning or psychomotor skills for clinical practice?" The search concepts therefore included teaching and training, scanning or psychomotor skills, and ultrasound or sonography.

6.2.2.2 *Stage two: Identify relevant studies*

The databases Ovid Medline, PubMed, CINAHL, ERIC, SCOPUS, as well as Flinders University search engine FindIt@Flinders, and the internet search engine Google Scholar were searched in 2012, and then up to the end of August 2019. Hand-searches of the *Australian Journal of Ultrasound in Medicine*, *Sound Effects*, and *Sonography Journal* were performed to identify profession-specific peer-reviewed literature. A review of grey literature on Australian Sonography Professional and Accreditation Websites was also undertaken to retrieve documents and data which may contribute to the knowledge and understanding of the review question. These latter two approaches were required to identify literature which may not have been detected by electronic searches.

A combination of Medical Subject Headings (MeSH), terms, and key words relevant to ultrasound, ultrasonography, and sonography, point-of-care, teaching, training, model or education, and scanning or psychomotor skills were combined using Boolean operators, and with the inclusion of "not" assessment, to perform the search (see Table 6.1 below). This strategy was used to ensure the focus of the retrieved literature was about the teaching of the foundation psychomotor scanning skills and not the competency of the learner's psychomotor scanning skills.

Table 6.1: Summary of the search terms used to explore the three search concepts

Profession/cohort	Pedagogical approach	Skill set	Expanded search terms
ultrasound **ultrasonography** **sonography**	teaching training training methods model education clinical education	psychomotor skills scanning skills transducer manipulation point-of-care	medical education undergraduate medical education obstetrics point-of-care (POC) ultrasound emergency ultrasound anaesthesiology anaesthetics midwifery radiology echocardiology cardiology cardiac

6.2.2.3 *Stage three: Study selection, inclusion and exclusion criteria*

Potentially appropriate articles were subjected to the following inclusion criteria:

1. Written in English.

2. Reported on or described using an educational approach to teach psychomotor scanning skills required for clinical practice.

3. Published between 1960-2019.

4. Included a narrative, overview, or report of the clinical teaching or supervision practices used to teach psychomotor scanning skills to sonographers or other cohorts.

Studies were excluded if they:

1. Only reported on the assessment outcomes of performing ultrasound or interventional skills.

2. Did not report or outline a skill-teaching approach to teach psychomotor scanning skills.

3. Described a clinical application of ultrasound without including the educational approach used to teach the scanning skill.

4. Described how to make phantoms to teach psychomotor scanning skills.

5. Reported on the integration of ultrasound imaging into a teaching curriculum.

Following the search, the duplicate papers were removed. The titles of the papers were scrutinised according to the inclusion and exclusion criteria. The abstracts of the remaining papers and theses were reviewed. The remaining literature was examined using the selection process outlined in Figure 6.1.
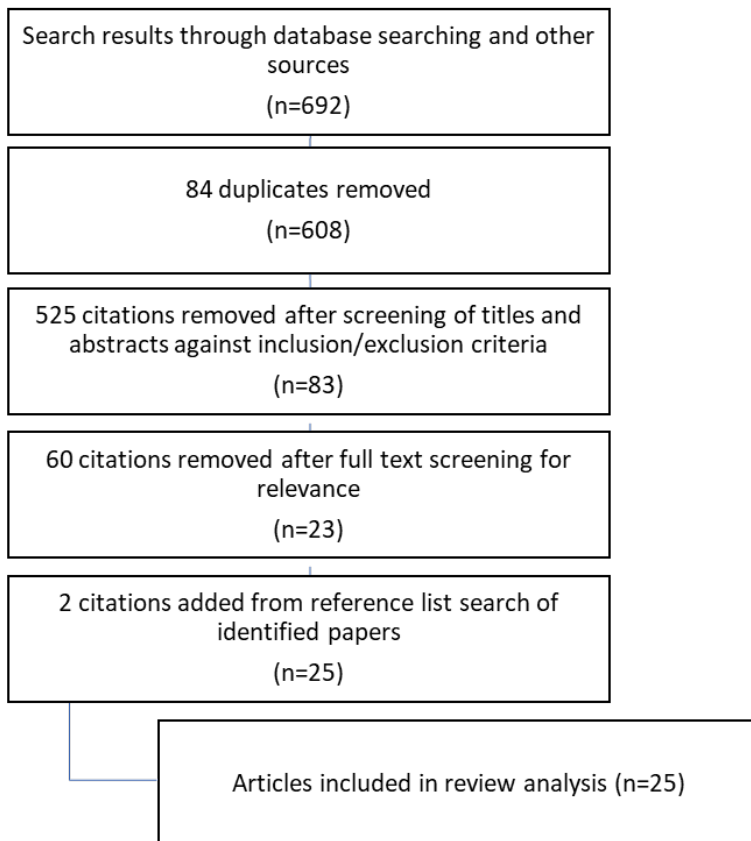
Figure 6.1: Flow diagram summarising the literature search

6.2.2.4 *Stage four: charting the data*

Between 2012 and 2019, a total of 25 pieces of literature were included in the final review, comprising:

1. Two grey governance documents.
2. Three review articles which report on some pedagogical approaches required to teach psychomotor scanning skills to sonographers, family medicine physicians, and point-of care ultrasound operators.
3. One narrative report which outlined strategies to teach psychomotor scanning skills to student sonographers in private practice.
4. Ten papers related to the skill set and the teaching practices reported by students and educators to teach psychomotor scanning skills.
5. Two papers reporting on systematic reviews related to teaching ultrasound psychomotor scanning skills by professions other than sonography.

6. One editorial report which described the steps to teach cardiac scanning to cardiology ultrasound operators.

7. Six articles which reported on the methods and outcomes from using several research methodologies to teach psychomotor scanning skills to three professional groups, including anaesthesiology, undergraduate medical education, and a mixed cohort group.

A summary table including each document was made (see Appendix 1). This stage involved extracting the main characteristics of each study and analysing the data for themes and gaps in the literature. The salient information from the retrieved literature was categorised using an analytical framework suggested by Arksey and O'Malley (2005). This structure was adopted to guide the process as there was limited guidance provided by Levac et al. (2010) on the strategies to use to extract the key data findings and the terms to use to populate a summary table.

6.2.2.5 *Stage five: Collating, summarising, and reporting the results*

The dominant themes to arise from the scoping review included:

- The research question had not been previously posed, researched, or published in a range of professional literature.

- The review identified that there was no definitive method used to teach psychomotor scanning skills. One reported approach used to teach psychomotor skills involved the educator first giving a didactic presentation on the theory related to performing the skill followed by providing a narrated skill demonstration and then supervising the learner's skill practice.

- The two-step or traditional model was highlighted as the most frequently used pedagogical approach to teach psychomotor scanning skills to sonographers and other disciplines who used ultrasound.

- Performing an ultrasound is an example of a complex psychomotor skill. The psychomotor scanning skills to move and manipulate the ultrasound transducer are also an example of a complex psychomotor skill. Therefore, when operators are first learning to perform the skill set required by both upper limbs, they are unable to perform both skill sets concurrently. Consequently, they learn the skill set in both upper limbs separately and then integrate their execution. Although, it is important to point out that the pedagogical approaches to teach these disparate skills was never explored.

- Simulation has a role to play when first teaching psychomotor scanning skills because the learner can focus on performing and refining the scanning skill without having to pay attention to the needs of the patient.

- There are few published studies which have explored dimensions of teaching and learning ultrasound psychomotor scanning skills: for example, the need for deliberate skill practice when acquiring psychomotor scanning skills. Most of the published studies have used research methods which have not enabled replication and they have used very small sample numbers. The remaining literature provided a descriptive analysis or synopsis. Therefore, there are important limitations related to the outcomes and interpretation of these data.

Results of the review are presented below and a summary of the key findings from the review are tabulated in Appendix 1.

6.2.2.6 *Stage six: Consultation is an optional step*

Levac et al. (2010) identifies that a consultative step may be required with external stakeholders when further clarification is required to contextualise or accurately interpret the research findings in the scope of the review. This step was not undertaken as there were very few papers which provided challenging data or complexities about current skill-teaching practice behaviours.

6.3 Results of the Literature Review: A Two-stage Review

The results of the literature review have been divided into two time points to ensure that the timeline and the chronology of the available articles is accurately portrayed within the project which has spanned nearly eight years. The first time point focuses on literature which was retrieved and published prior to January 2013. For that initial review, the cohort was limited to ultrasonographers because the research question was focused on this professional group. The second time point included the period from January 2013 up until the end of August 2019. At this stage, the cohort group was expanded to include research from other professional cohorts who have reported on the instructional approaches and pedagogy related to teaching psychomotor scanning skills required for a broad scope of clinical applications of ultrasound. This cohort included various sub-specialties of medicine and allied health.

6.3.1 Initial literature review results (up to 2013)

Prior to January 2013, there were only three papers which contributed to the initial literature review (Sonaggera, 2004; Brown et al., 2011; Thoirs & Coffee, 2012). This lack of literature justified the research project. A review of the three papers resulted in a number of initial outcomes for the thesis, as listed below and explained in greater detail in the following sections:

1. A summary of the study participants and methodology used by the researchers.
2. The reinforcement of the implicit knowledge that psychomotor scanning skills are just one of the components required to perform an ultrasound examination safely.
3. An outline of some of the instructional approaches used by the sonography profession to teach psychomotor scanning skills.
4. The creation of a synopsis of the key findings of the two literature reviews (conducted at differing time points).

6.3.2 Professional practice background of the participants, study location, and methodology

The area of professional clinical practice reported by the participants performing ultrasound included: general sonography in the United States of America (Sonaggera, 2004); cardiac sonography in Australia (Brown et al., 2011); and musculoskeletal sonography in Australia (Thoirs & Coffee, 2012).

Differing methodologies were used for the three research projects. Two of the articles used surveys and qualitative data (Sonaggera, 2004; Brown et al., 2011) to explore the perceptions of students and sonographer educators when teaching psychomotor scanning skills. The third article explored the skill acquisition outcomes of a mixed cohort of sonographers to perform a range of foot and ankle tendon scans with the novel use of a DVD as a teaching tool (Thoirs & Coffee 2012). Interviews were conducted to explore the outcomes of the teaching intervention (Thoirs & Coffee 2012). Small sample sizes were evident in all studies. Sonaggera (2004) reported on the responses of 41 student sonographers. Brown et al. (2011) reported on eight qualified and four student sonographers. Thoirs and Coffee (2012) documented the skill acquisition of a small (n=5) mixed cohort of students and recently accredited sonographers: it was not specified how many participants were in each group. All studies used real patients to acquire and practice their psychomotor scanning skills. In all three studies, there was a lack of demographic information about the student participants and sonographer educators.

Sonaggera (2004) developed a small survey to explore the perceptions of American student sonographers who were completing their sonography credentialing. It is unclear how many questions were included in the survey. However, five questions were presented in the article. The items were diverse and ranged from asking, "Do students prefer to practice scanning before or after the sonographer?" to exploring, "What are some characteristics of an ideal clinical instructor and clinical rotation?" (Sonaggera, 2004, pp. 356-357). The survey was distributed via the Society of Diagnostic Medical Sonography discussion forum to student sonographers across America. There was no data provided on the number of student sonographers registered with the Society of Diagnostic Medical Sonography when the survey was administered, and a survey response rate was not provided. The method of analysing the data was not described and no demographic data of the participants was provided. However, the results to the questions suggest that content analysis was performed. Sonaggera (2004) published the first identifiable literature on this area of sonography education but provides limited critical analysis of the student perceptions and findings. The author identified that novice and advanced students had differing teaching and learning requirements, and that the sonographer educator's willingness and preparedness to support a learner's skill and knowledge development affected the student's clinical practice and educational outcomes. A major finding of Sonaggera (2004, p. 356) was that sonographers "mimic the transducer manipulation and techniques they just watched". This is the first identifiable record in the ultrasound literature which points out the need for observational practice (Spittle, 2013; Schmidt et al., 2019); although, Sonaggera (2004) does not specifically use this term. It is important to point out again that there was very little information on this topic at the time of publication.

Brown et al. (2011) explored the sonographer educators' use of consistent terminology to teach cardiac psychomotor scanning skills: notably, transducer manipulation. The teaching group of clinical supervisors and students were employed in clinical departments located in Canberra, Australia. Evaluation forms were developed to explore the educators' perceptions and barriers to teaching psychomotor scanning skills in clinical practice. Additionally, perceptions were sought from those students who were taught transducer manipulation and other psychomotor scanning skills. The questions used to explore the research area were not outlined, nor was a response rate. The demographic data of the participants was not outlined. The process used to analyse the qualitative data was not described. Nevertheless, the research provides important insights and perceptions about the difficulties reported by the supervisors to teach psychomotor scanning

skills. All the supervisors identified that the most challenging skill was to teach was transducer manipulation. The educators identified many factors which exacerbated the difficulty of teaching and learning this skill. Three key points from the research were that sonographer educators: did not have enough time to always provide enough hands-on scanning practice; found it a challenge to deconstruct and then explain the large and small transducer movements needed to image the cardiac anatomy; and had to undertake an informal clinical teaching role without the knowledge or skills to do so. Therefore, one of the salient findings from the research was that sonographer educators needed additional credentialing in clinical education to assist their education role (Brown et al., 2011, p. 15).

Thoirs and Coffee (2012) performed a small pilot trial of five students and recently qualified sonographers learning the skills to perform foot and ankle MSK ultrasound over a three-month period using a DVD-based teaching tool. Thoirs and Coffee (2012) provided no further professional practice or demographic details about the cohort. The DVD was used for self-directed skill acquisition of sonography students for scanning and imaging a range of foot and ankle tendons. The study included post-assessment interviews. However, while the three themes of the interview analysis were clearly stated, the researchers did not include the questions posed to the five participants. Thoirs and Coffee (2012) argued that a controlled study was not required for this research project. Although the sample number was small, Thoirs and Coffee (2012) conclude that educators and learners benefited from using a structured approach when skills are taught and learned.

6.3.3 Performing an ultrasound examination: psychomotor scanning skills are just one of the components

The psychomotor scanning skills needed to acquire diagnostic ultrasound images are just one component of the broader knowledge and skill set required to safely and accurately perform an ultrasound examination (Sonaggera, 2004; Brown et al., 2011; Thoirs & Coffee, 2012). Nevertheless, the cornerstone of each examination is founded on the operator having developed psychomotor scanning skills. Indeed, Thoirs and Coffee (2012, p. 703) point out that performing an ultrasound relies on the operator being able to "skilfully manipulate ultrasound equipment". This statement suggests that not only does the operator need to learn how to move and manipulate the ultrasound transducer, but they are also required to use and optimise the machine controls and settings, or ultrasound equipment. Brown et al. (2011) assert that the skill to move and manipulate the transducer is both a fundamental and antecedent skill to being able to

demonstrate the anatomical structure ultrasonically. This is because, a good 2D image must be acquired before the operator can accurately assess and evaluate the organ or structure's function and haemodynamic properties with spectral Doppler. This imaging principle is true for all types of ultrasound examinations, including 3D ultrasound.

There is consensus among all three papers that, for most novice operators, acquiring the skill of moving and manipulating the transducer to perform an ultrasound examination is difficult. This is because performing an ultrasound examination is an example of a complex psychomotor skill. For example, Sonaggera (2004) points out that visualising an organ with ultrasound relies on the operator moving the transducer through a combination of multi-directional movements. She argues that gaining this practice knowledge can be a challenge for novice operators. Additionally, Brown et al. (2011) concluded that the skill of moving the transducer is both difficult to teach and to learn. Indeed, Brown et al. (2011) reported that educators identified that transducer manipulation is one of the most onerous psychomotor skills to teach to novice operators. However, the authors did not expand upon their analyses of this statement. Brown et al. (2011) point out that moving and manipulating the transducer uses a combination of fine and gross motor skills to obtain specific images, and for novice operators this practice knowledge is yet to be learned. Both Sonaggera (2004) and Brown et al. (2011) found that, for students to become familiar with the combination of transducer movements, they require verbal and hand-on-hand or physical guidance. The research by Thoirs and Coffee (2012) revealed that one of the most important benefits of face-to-face clinical teaching was receiving real-time feedback and guidance about their practice performance from the sonographer educator. Verbal and physical guidance are examples of sensory information provided by the educator to the learner about the execution of their motor actions. Auditory or physical information provided to the learner are forms of feedback. There is very little empirical data about the type, quantity, and timing of feedback provided by sonographer educators to learners during or at the completion of an ultrasound examination.

6.3.4 The instructional practices used to teach psychomotor scanning skills circa 2013

It is asserted by Thoirs and Coffee (2012) that the knowledge linked to performing a psychomotor skill by sonography students is usually taught through didactic lectures, and the skills themselves are taught using a model which involves demonstration and observation followed by practice – also known as the two-step skill-teaching approach (Archer et al., 2015). In 2013, there was limited empirical evidence of what instructional approaches were used by sonographers to teach

psychomotor scanning skills. Of the three articles reviewed, only the one by Thoirs and Coffee (2012) reported that the primary goal of their article, from a small pilot trial of five participants, was to explore the teaching and learning outcomes that resulted from using a given pedagogical approach. Brown et al. (2011) and Sonaggera (2004) aimed to explore the student skill-teaching and clinical education perceptions rather than outcomes. It is suggested, but not overtly stated, by Sonaggera (2004) and Brown et al. (2011) that a master-apprentice instructional approach was used to teach psychomotor scanning skills to sonographers performing general and cardiac sonography respectively. Brown et al. (2011) and Sonaggera (2004) did not specifically use the phrase 'master-apprentice teaching approach' to represent the skill-teaching practices they reported. For example, Sonaggera (2004) pointed out that teaching psychomotor scanning skills relied on the educator demonstrating what the skill should look like, how to place, move, and manipulate the transducer, how to use the keyboard and access the menus, the appearances of normal sonographic anatomy, and a scan protocol for a given area of interest. Having demonstrated the exemplar of performance, the learner tries to imitate this standard in their clinical practice. Brown et al. (2011) similarly stated that novice cardiac sonographers practiced performing the examination while the sonographer educator directed the teaching and learning process. In addition, Brown et al. (2011) made the point that the teaching approach can also be ad hoc due to the limited clinical teaching knowledge of the sonographers – that they are trying to provide teaching and practise opportunities when there is a fully booked list of patients.

There is some research to suggest that the learning preferences of novice and advanced sonography students differ. In one paper, Sonaggera (2004) reported that novices preferred to scan after the educator. The learners indicated that this approach enabled them to observe the skill practice, how to position the patient, how to move and place the transducer on the patient's skin, and where to place the callipers on the organ to measure the structure. The students then tried to replicate the educator's practice performance. The educator provided additional support by adjusting the machine image and instrumentation factors (because students had not yet taught where to locate the knobs and buttons on the keyboards and how to access and adjust the main and sub-menu functions). During the early stages of learning psychomotor scanning skills, the sonographer educators also provided verbal and/or physical guidance (Sonaggera, 2004). Students reported that they found it beneficial for the tutor to hold their scanning hand and then jointly guide and move the transducer to get the required image as they struggled to replicate the quality of the tutor's image. Brown et al. (2011) also reported that verbal guidance or hand-on-hand

physical guidance was the most common assistance provided by the educator to the student when teaching psychomotor scanning skills. Brown et al (2011) further found that, in order to be able to direct the learner to modify their transducer movements, both the educator and the student needed consensus on the nomenclature for the intended movement outcomes, after which the sonographer educators needed to be consistent in their use of those terms. Educators also needed to provide enough hands-on scanning time to enable the learner to progress their skill development. However, they provide no empirical data about the use, type, and timing of sensory feedback to support the acquisition of psychomotor scanning skills.

The student's level of ability also affected learner preference. Sonaggera (2004) found that more advanced students indicated that they had differing learning preferences to those reported by novice sonographers. For example, advanced students preferred to scan the patient prior to the educator scanning, and complete as much of the ultrasound examination as possible. They then indicated that they wanted to observe how the educator obtains and documents any images that they were unable to acquire, or which more accurately depict the pathology present. Also, the advanced students reported that they appreciated receiving feedback about their practice performance. Sonaggera (2004) alluded to distinct and contrasting teaching and learning approaches for beginner and advanced sonography students. It is suggested by this limited review that these and other specific pedagogical approaches are required when a scanning skill is being taught and learned. At that stage, there were limited investigations about how the sonography profession taught psychomotor scanning skills.

Thoirs and Coffee (2012) used an instructional approach which involved skill demonstration and observation followed by skill practice for scanning a range of foot and ankle tendons. For this study, most of the time the participants engaged in non-supervised skill practice. It is difficult to deconstruct from the report what the application and benefit of using a DVD teaching tool was to teach MSK psychomotor scanning skills. This is because the cohort was comprised of participants with varying skill abilities and credentialing. Consequently, it is unclear whether this cohort variability played an important role in some participants being able to perform a wider range of moderately difficult to difficult psychomotor scanning skills, compared to other participants. Conversely, other factors such as the variable amount of skill practice or feedback provided during, and at the conclusion of, the skill practice may have influenced the results. Because of the methodology used, these distinctions cannot be deduced from the report. Nevertheless, Thoirs and Coffee (2012) asserted that performing an MSK ultrasound ranged in complexity from easy to

difficult. According to the authors, learning to scan the Achilles tendon is an example of an easy task, whereas imaging the spring ligament is an example of a difficult ultrasound skill. Thoirs and Coffee (2012) did not provide a rationale for this skill classification. They asserted that this group of foot and ankle tendons can be aggregated into four categories representative of the degree of difficulty to learn the task: easy, moderately easy, moderately difficult, and difficult. However, Thoirs and Coffee (2012, p. 706) contradicted the aforementioned statement by claiming that, "Most skills demonstrated in the DVD were considered advanced skills not included at entry level practitioner training". Therefore, if this statement is correct, then the research project had an inappropriate sample because the skills being taught to some of the cohort were beyond the purview and scope of their skill level. Interestingly, all five participants were able to scan the Achilles tendon to a predetermined level of competence after using the two-step teaching approach. The speculated difficulty by the authors to scan some of the ankle and foot tendons may explain why only one participant was able to adequately image the tendons grouped into the difficult category using this teaching approach. This finding prompted Thoirs and Coffee (2012) to suggest that an alternative teaching approach may be required when the skill is classed as difficult and complex.

6.4   Summary of Initial Review 2012-2013

In 2013, there was little empirical data about the specific instructional practices that sonographers used to teach psychomotor scanning skills. This initial review suggests that novices observed an experienced sonographer demonstrate the clinical scanning skills and then practised with a variable amount of supervision and feedback. There was little information about the specific pedagogical approaches that the sonography profession used to demonstrate the skill, whether the sonographer educator provided an overlay of commentary as they taught the skill, and what other instructional approaches were used to support the learners' skill acquisition. There was very little information and data about which practice schedules and formats (long or short and blocked or random skill practice sessions) facilitated the optimal conditions for the acquisition, performance, and learning of complex psychomotor skills. Likewise, there was a lack of information about the type, quantity, and timing of the feedback provided by educators during and at the conclusion of a practice performance. Without this data and knowledge, the teaching practices cannot be reviewed and compared to the published theories and principles of teaching and learning the psychomotor skills. This initial review highlighted the lack of research outlining a robust and defensible methodology to explore how psychomotor scanning skills were taught in

clinical practice and this limits the ability to replicate the studies and compare study findings. There is also a lack of appropriately powered studies on the research topic; therefore, the results should be cautiously reviewed and interpreted. Nevertheless, there was a global lack of data and knowledge about the instructional approaches used to teach the psychomotor skills required to perform an ultrasound. Therefore, the research question proposed in 2012 was "What are the pedagogical approaches used by Australian sonographers to teach psychomotor scanning skills required for clinical practice?"

6.5 Insights and Knowledge from the Integration of Additional Literature Up to August 2019

Following the initial review in 2013, further literature was published on the research topic by sonography professionals and the Australasian Sonographers Association. Other disciplines also published their insights, reflections, research, and, more recently, meta-analyses of the teaching approaches used by these cohorts in their clinical practice. Consequently, the scope of the literature review was expanded to include the articles of those professions: since 2013, a further 22 pieces of literature have been added, including two policy documents published by the Australasian Sonographers Association. The remaining 20 publications reported on aspects related to teaching a psychomotor skill, authored by a wide range of health professions, including one that has been included as Chapter 2 of this thesis.

The next sections will present the findings from these additional publications, with these key findings covered: show that performing an ultrasound examination is an example of a multidimensional skill; report that the psychomotor scanning skills used to perform an ultrasound are an example of a complex skill; outline the pedagogical approaches that are being used to teach the psychomotor scanning skills required for clinical practice; and finally, explore the role of simulation to teach psychomotor scanning skills.

6.5.1 Performing an ultrasound is a multi-dimensional skill

To perform each ultrasound examination, an operator requires a broad range of theoretical knowledge and the psychomotor skills to be able to safely perform the scan (Dresang, Rodney, & Dees, 2004; Nicholls et al., 2014; Gibbs, 2015). These and other professional practice dimensions of knowledge and skill are woven throughout the ultrasound examination, and they must be first taught and then learned by the operator. For example, the learner must have knowledge of: the physics of ultrasound (Dresang et al., 2004; Ryan, 2017); the anatomy, physiology, and

pathophysiology of the organ system (Lavender et al., 2016); the machine functions and their location on the keyboard (Sonaggera, 2004); the patient positioning and acoustic windows used to scan the organ (Sonaggera, 2004; Lavender et al., 2016); the clinical decision making (Gibbs, 2015; Ryan, 2017); the probe manipulation skills required to identify and then survey scan the organ (Dresang et al., 2004; Brown et al., 2011; Australasian Sonographers Association, 2011); the suggested imaging protocols (Dresang et al., 2004; Ryan, 2017); the standards of imaging performance for a given organ or structure (Australasian Sonographers Association, 2011); the communication skills to talk to the patient (Crofts, 2015; Ryan, 2017); and the evidence-based diagnostic criteria (Lavender et al., 2016). Cognition of these knowledge, skill, and professional practice domains are required before an operator can safely perform, document, interpret, and write up a provisional report of the ultrasound findings (Thoirs & Coffee, 2012; Crofts, 2015; Gibbs, 2015; Lavender et al., 2016; Ryan, 2017; Pessin & Tang-Simmons, 2017; Edwards, Chamunyonga, & Clarke, 2018). The quality and accuracy of the ultrasound examination is reliant upon the operator being appropriately trained (Australasian Sonographers Association, 2011; Ryan, 2017; Edwards et al., 2018). It is the instructional practices used to teach the psychomotor scanning skills which are the focus of this research and thesis.

Performing most ultrasound examinations requires the operator to use both upper limbs to execute disparate motor actions, or psychomotor skills, to manipulate the transducer and to perform image optimisation and instrumentation. Many of these psychomotor skills are performed concurrently (Edwards et al., 2018). Operators learn with ongoing clinical practice that image optimisation and instrumentation impact and affect the diagnostic quality of the ultrasound image (Gibbs, 2015). Therefore, both upper limb skill sets are required to produce a diagnostic ultrasound image. The image of the displayed 3D anatomical structure is usually demonstrated in 2D on the ultrasound monitor. Visuo-motor psychomotor scanning skills refers to the relationship between adjusting the position of the transducer on the patient's skin and/or changing the combination of the transducer arcs and angles, and gaining an understanding of how these actions modifies the displayed ultrasound image on the 2D monitor (Nicholls et al., 2014; Montealegre-Gallegos, Pal, & Matyal, 2014; Gibbs, 2015; Ryan, 2017). Whereas, visuo-spatial skills refer to the ability of the operator to sweep the ultrasound beam through the organ, using multiple scan planes, and a 3D mental image of the anatomical structure and its spatial anatomical relationships is created from the displayed 2D images (Nicholls et al., 2014).

It is difficult for a novice to perform concurrent cognitive and manual skills because of the large quantity of information to process (Gibbs, 2015). Therefore, there are several authors who state that the skills needed to perform image optimisation and instrumentation, often referred to as knobology, should initially be taught separately to the probe manipulation skills (Arger, Schultz, Sehgal, Cary, & Aronchick, 2005; Thoirs & Coffee, 2012; Crofts, 2015). Crofts (2015) importantly observed that a small cohort of novice learners were not able to perform both skill sets concurrently. The novice learner could either manipulate the transducer or perform image instrumentation and optimisation, but not both simultaneously. Significantly, Crofts (2015) witnessed that when the novice learner attempted to perform dual upper limb tasks concurrently they were unable to do so. When the novice tried to move the transducer and perform knobology skills at the same time, they stopped scanning while they then adjusted the toggles and keys on the machine, after which they resumed moving the transducer and scanning. However, no theoretical explanation for these reported behaviours was provided. The practice of isolating the teaching and learning of the knobology skills was reported by Sonaggera (2004), who pointed out that the sonographer educator stood beside the machine and performed image optimisation and instrumentation while novice operators were scanning. However, the reason cited for this assistance, by Sonaggera (2004), was that the learner had not yet been taught and become familiar with the keys and functions of the ultrasound machine. Therefore, there is a small body of evidence which suggests that the way educators teach scanning skills needs to be further researched. This is an example of how there is not enough scholarship and baseline research on the instructional approaches being used to teach scanning skills.

6.5.2   Scanning skills are an example of a complex skill

The scanning skills required to perform an ultrasound are complex; they are multi-dimensional and also vary in difficulty (Thoirs & Coffee, 2012; Nicholls et al., 2014; Crofts, 2015; Gibbs, 2015; Lavender et al., 2016). Thoirs and Coffee (2012) pointed out that scanning skills to perform sonography of the foot and ankle tendons can be classified across a continuum from simple to advanced. However, the authors did not provide a classification system for each of the categories used to assign each class of skill complexity. While it is logical for sonographer educators to intuitively understand that the scanning of an Achilles tendon differs in complexity to that of performing an 18-20 week fetal morphology scan, there has been very little research and literature which has analysed the concept and construct of one skill being simple and the other complex.

Nevertheless, there is enduring merit in the educational literature for educators to adopt an approach when teaching psychomotor skills to teach those which are simple and then progressively advance to teach more complex skills. Montealegre-Gallegos et al. (2014), from a cardiac background, argued that the psychomotor skills required for clinical practice should be scaffolded, beginning with learning the simple skills related to performing a task and then progressing to the more advanced tasks. Montealegre-Gallegos et al. (2014) also argued that, when teaching a complex skill such as those required to perform transoesophageal echocardiography, the educator should isolate a sub-component of the whole task and teach this part first, before advancing to the next sub-component. Despite this, there is very little published data which reports on the use and teaching and learning outcomes in ultrasound from instructional approaches which involve task analysis and task deconstruction. Meadley, Olaussen, Delorenzo, Roder, Martin, St Clair, Burns, Stam, and Williams (2017), reported that the instructional approach did not differ when educators taught paramedics a range of POCUS scanning skills, which included learning to perform cardiac, lung, peripheral venous access, long bone fractures, Focused Assessment Sonography for Trauma (FAST), and the location of endotracheal tube placement. While there is no rubric which provides a classification system to categorise less and more complex scanning skills, it can be reasonably argued that the skill to perform a cardiac scan differs in complexity to assessing the lung and pleural space ultrasound. Therefore, there have been contrasting accounts of the instructional approaches used by different disciplines within the health professional arena to teach scanning skills.

6.5.3 The continuation of the literature review and the expansion to include other professions who use ultrasound imaging

The scoping review of this thesis was progressively updated to include subsequent publications by authors from the sonography profession. Additionally, the review was expanded to include literature from other professions who used and taught ultrasound scanning skills. A broad range of disciplines have published literature that is relevant to the review question, and these professions include anaesthesiology (Ahmed, Azher, Gallagher, Breslin, O'Donnell, & Shorten, 2018), intensive care (Sultan, Shorten, & Iohom, 2013), paramedics (Meadley et al., 2017), critical care (Greenstein, Littauer, Narasimhan, Mayo, & Koenig, 2017), undergraduate medical education (Arger et al., 2005; Davis, Wessner, Potts, Au, Pohl, & Fields, 2018), pre-clinical medical education (Webb, Cotton, Kane, Straus, Topp, & Naeger, 2014), cardiology (Montealegre-Gallegos et al., 2014), point-of-care ultrasound (POCUS) (Moore & Copel, 2011; Cartier, Skinner, & Laselle, 2014), and family medicine (Dresang et al., 2004). Therefore, these professions have contributed to the body

of knowledge on the review questions because their articles have reported on the pedagogical approaches used to teach scanning skills in disciplines other than sonography.

6.5.4 The pedagogical approaches used to teach scanning skills by sonographers and other disciplines of medicine

Globally, for more than seven years, sonographer educators have been pointing out in the literature the insufficient attention and sparse research about pedagogical approaches used to teach sonographers psychomotor scanning skills (Thoirs & Coffee, 2012; Crofts, 2015; Thoirs et al., 2016; Edwards et al., 2018). Examination of the papers in the scoping review showed that the most common pedagogical approach to teach ultrasound involved a combination of didactic lectures, skill demonstration, and observation, followed by supervised skill practice (Dresang et al., 2004; Arger et al., 2005; Moore & Copel, 2011; Montealegre-Gallegos et al., 2014; Cartier et al., 2014; Thoirs et al., 2016; Greenstein et al., 2017; Ahmed et al., 2018). To explain further, the skill demonstration was usually accompanied by a concurrent verbal overlay by the educator about the steps and requirements to perform the skill (Moore & Copel, 2011). When the expert demonstrated the skill, it was without any errors (Montealegre-Gallegos et al., 2014; Cartier et al., 2014). This is because the skill demonstration provides the learner with a visual exemplar or standard of performance for the task (Montealegre-Gallegos et al., 2014; Cartier et al., 2014). Next, the student practiced the skill under guided supervision, where feedback may be provided by the educator during (Sonaggera, 2004; Pessin & Tang-Simmons, 2017), or at the conclusion of the skill practice (Australasian Sonographers Association, 2015; Crofts, 2015; Lavender et al., 2016). Importantly, the feedback at the end of the performance was ideally learner-focused, objective, detailed, and targeted to the level of the learner's clinical experience (Thoirs & Coffee, 2012; Sultan et al., 2013; Crofts, 2015; Edwards et al., 2018). This teaching approach is referred to in the literature by several names: the apprenticeship model (Sultan et al., 2013), master-apprentice skill-teaching approach (Dresang et al., 2004; Arger et al., 2005; Montealegre-Gallegos et al., 2014; Lavender et al., 2016; Meadley et al., 2017), two-stage instructional approach, or the " see one, do one" method (Australasian Sonographers Association, 2015).

The ASA (2015) suggested in a governance document that sonographers in Australia should use the four-step instructional approach published by Walker and Peyton (1998) to teach psychomotor scanning skills. The first step, demonstration, involved the sonographer educator performing the task at a normal pace. The second step, deconstruction, involved the educator slowly performing the skill while providing a verbal description of the steps. Next, comprehension, required the

educator to execute the skill while the learner describes the steps. Finally, performance, relied on the learner executing the skill as they recalled and described the steps. There is no identifiable theory or practice evidence to support the ASA advocating for this model to be used to teach psychomotor scanning skills. It is unclear why this model was selected ahead of other published motor-learning domain skill-teaching approaches to teach psychomotor scanning skills.

6.5.5 Simulation: a pedagogical approach used to teach psychomotor scanning skills

Simulation has appeared as a theme in the literature. Simulation provides an opportunity for learners to practice skills without having to also focus on the clinical needs of the patient. Additionally, teaching basic psychomotor scanning skills using simulation enables the opportunity for psychomotor skills to be isolated and deliberately or repeatedly practised until the learner becomes confident performing that task (Sultan et al., 2013; Gibbs, 2014, 2015; Pessin & Tang-Simmons, 2017), after which they can advance to performing more involved and complicated psychomotor scanning skills. Another benefit of using simulation is that scanning errors can be made without fear of harm to the patient (Pessin & Tang-Simmons, 2017). However, it is important for the educator to correct novice's scanning errors immediately when they occur by providing verbal or physical guidance because the learner is often not aware that the task has been incorrectly executed in the initial stages of acquiring the psychomotor skills to perform the task. Davis et al. (2018), in a systematic review which explored the instructional practices used to teach undergraduate medical students ultrasound psychomotor scanning skills, found that simulation was just one approach used to teach scanning skills. Indeed, psychomotor scanning skills were also taught using peer students, healthy volunteers, patients, standardised patients, cadavers, and animal models. There are strengths and weaknesses to using each of these simulated practice conditions. For example, simulation cannot be used for some tasks, i.e. a known limitation is that most testicular (Pessin & Tang-Simmons, 2017) and pregnancy phantoms do not replicate the normal scrotal and myometrial blood flow and perfusion. Therefore, these skills cannot be authentically rehearsed during skill practice. Another limitation is how the tactile experience, haptics, of using the simulation tool replicates practice on a real patient (Gibbs, 2015; Pessin & Tang-Simmons, 2017). These tactile skills need to be first taught and then learned to ensure that they are correctly transferred during authentic clinical practice. Therefore, the learning objectives for each teaching session that uses simulation should be aligned with the teaching possibilities for the specific simulation phantom (Pessin & Tang-Simmons, 2017). There is

very little literature which compared the teaching and learning outcomes, as well as skill retention, using these differing approaches.

6.6   Limitations

A limitation of this review is that only one person critiqued the abstracts and papers. Levac et al. (2010) and Arksey and O'Malley (2005) suggest that two reviewers should analyse the abstracts, review all literature included in the review, and extract the key themes and main data outcomes required in stage four of the framework. A further limitation is that the keywords used to harvest the relevant literature may not have identified all the papers related to the research topic.

6.7   Summary

The critical review of the 25 articles found that most of the psychomotor scanning skills required for clinical practice among a range of professional groups have been taught using a master-apprentice skill-teaching approach. It is clear from the analysis that there has been little research and attention paid to the specific instructional approaches that are being used to teach psychomotor scanning skills, why these practices are being used, and with what frequency. Additionally, there has been insufficient research which has been appropriately powered to be able to draw meaningful conclusions from the data.

There is currently a knowledge gap in the literature. To fill this gap, the aim of this study was to explore how Australian sonographers teach scanning or psychomotor skills required for clinical practice. The second part of this dissertation outlines the research methodology, steps to purposefully develop a survey instrument to use as a measurement tool, and the results from undertaking a national survey of sonographers.

PART TWO: THE RESEARCH METHODOLOGY, RESEARCH DESIGN, ITERATIVE RESULTS OF THE DEVELEMENT OF A SURVEY TOOL, THE NATIONAL SURVEY RESULT, LIMITATIONS, AND CONCLUSION.

7   METHODOLOGY

This chapter explains and justifies the research design and methodology used to gather the knowledge and data to answer the research question. The overarching goal of this research was to garner baseline information about the instructional practices that are being used by Australian sonographers to teach scanning skills. A cross-sectional research survey design approach was used to explore how sonographers teach scanning skills. A purposefully developed and partially validated survey instrument was used to explore the five main domains related to teaching scanning skills.

7.1   The Rationale for Researching How Psychomotor Skills are Taught in Clinical Practice

Performing an ultrasound examination requires the operator to integrate multiple domains of knowledge, skills (scanning and communication), clinical reasoning, decision making, and professional practice abilities. While each of these domains is important to the performance of the examination, the focus of this dissertation has been to concentrate on the psychomotor skills that are used to perform an ultrasound examination. Therefore, these other domains will not be studied in this thesis.

A primary outcome from the literature review was that there was a substantial lack of research which explored how sonographers, or other disciplines who used ultrasound imaging, taught the psychomotor scanning skills that are required for clinical practice. Another finding of the review was that most studies had reported on outcomes based on very small sample numbers; therefore, the representativeness of the results to the broader population have not yet been adequately established (Sarantakos, 2013). Relying on the search outcomes from small sample numbers is problematic because the conclusions that can be made between the research variable(s), intervention, and population are tenuous (Creswell, 2008; Sarantakos, 2013). Another notable limitation of many of the previous studies is that the research methods used did not permit the studies to be replicated. Creswell (2008) argues that it is essential that the study's research methods are not mixed, and they are described in sufficient detail to enable the research to be

repeated. Therefore, these two factors strongly influenced the research design and methodology selected for this research project.

The psychomotor skills that are used to perform an ultrasound examination are an example of a complex psychomotor skill. In Chapter 4, the published motor-learning theories and principles related to teaching and learning a complex psychomotor skill were reviewed. A major finding of this review was that psychomotor skills are acquired in stages and at each stage differing pedagogical approaches are required to support the learner's acquisition and performance of the complex psychomotor skill. Despite the endurance and acceptance of this research, to guide the teaching and learning of psychomotor skills, there remains very little empirical research which explores whether these pedagogical approaches are being used by sonographers to teach complex psychomotor skills. Indeed, a major finding of the literature review was there have been very few studies which have intentionally explored how psychomotor scanning skills are taught by sonographers. Furthermore, there have been no studies which have purposefully researched how the Australian sonography profession teaches psychomotor scanning skills; therefore, the research question was posed, "What pedagogical approaches are used by Australian sonographers to teach psychomotor scanning skills required for clinical practice?" The goal of this research was to garner inaugural and baseline data about the teaching approaches used by the profession who perform ultrasound examinations across Australia. The research question was intentionally and deliberately broad. This is because it was important to first capture a panoramic view of the teaching approaches used by the profession. This knowledge could then be used to buttress the results of subsequent and focussed research surrounding the topics related to the teaching of psychomotor scanning skills by sonographers.

7.2   The Use of a Cross-sectional Survey Design Approach to Identify the Skill-teaching Trends and Behaviours Used by Australian Sonographers.

This study used a cross-sectional survey design approach to identify the skill-teaching behaviours and practices used by Australian sonographers to teach psychomotor scanning skills. A cross-sectional survey design involves collecting data at one point in time from a target sample about their perceptions and behaviours (Creswell, 2008). Using this research approach provides data about the trends in the behaviour of a population (Creswell, 2008). Creswell (2008, p. 389) argues that the advantage of using a cross-sectional survey design approach includes it "can examine current attitudes, beliefs, opinions, or practices" that are related to the research topic. These benefits were important for the exploration of this research topic which was scoping inaugural and

baseline information about the teaching practices used to teach complex psychomotor skills. Consequently, other qualitative or combined research designs, for example grounded theory, ethnographic, and mixed methods designs, were not considered for this research project. This is because the research design and methodology of these approaches were not aligned to a post-positivist approach and they would not provide the type, quantity, and format of data that could answer the research question.

Creswell (2008, p. 59) outlines that there are three components required to undertake educational research. The three interconnected factors include: (1) the six steps performed throughout the research process, (2) to determine and analyse whether qualitative or quantitative approaches and data are to be or were used at each of these six steps, and (3) the type of research design must be able to collect the type of data which can answer the research question. For example, qualitative data is captured using specific approaches and used for ethnography, grounded theory, and narrative research designs. In contrast, there is a strong bias to collect mostly quantitative data when using a survey approach.

There was no previous profession-based and published research to guide the methodology of this research project; therefore, to undertake this educational research, I began by sequentially moving through each of the six steps outlined by Creswell (2008). These steps included:

1. Identifying the research problem.
2. Undertaking a literature review.
3. Articulating the goal and purpose of the research.
4. Performing data collection.
5. Completing data analysis.
6. Evaluating and reporting the research.

In Chapter 1, the research problem and the lack of literature on the research topic was identified. Several topic-related literature reviews were undertaken and a further and larger scoping review (see Chapters two to six). These reviews provided progressive evidence that the research topic had not been previously researched and that there was very little published literature which was profession-specific to the field of medical ultrasound imaging. For example, in Chapter 3, it was proposed that scanning or psychomotor skills could be classified as either simple or complex. While in Chapter 4, a review of the motor-learning theory and principles to teach a psychomotor skill identified the pedagogical steps required to teach and learn a complex psychomotor skill. The

central tenet of these theories is that the pedagogical approaches that are used by educators to teach complex psychomotor skills differ to those used to teach simple psychomotor skills. To do so maximises a learner's cognition and skill acquisition of a complex psychomotor skill.

Additionally, the scoping review in Chapter 6 identified that there was very little research by sonographers (or other users of diagnostic ultrasound imaging) which had used large sample numbers and a research method which could be replicated. Furthermore, this review also identified that research question had not previously been studied and published. The scoping review also suggested that the two-step skill-teaching model was being used to teach psychomotor scanning skills to some sonographers and other health professional cohorts. However, there was no empirical evidence to support this finding. Therefore, the primary goal of the research was to explore and determine the teaching approaches, or behaviours, that are used by sonographers to teach psychomotor scanning skills across Australia. Another goal was to verify whether the two-step model was being used to teach psychomotor scanning skills and/or whether the profession was using heuristic approaches to teach these skills.

This study will take a post-positivist scientific research approach to answer the research questions (Cleland & Durning, 2015). Using a post-positivist lens of enquiry balances the need for the creation of an evidenced-based reality (referred to as positivism) and the need to gain a meaningful understanding of the skill-teaching perceptions and behaviours of Australian sonographers (referred to as interpretivism) (Cleland & Durning, 2015). Situated within the post-positivism paradigm, this study sought to explore the skill-teaching practices of a professional cohort and whether other suggested pedagogical approaches were also being used to teach complex psychomotor skills. The post-positivist paradigm involves developing evidence about a research topic while acknowledging that elucidating all the facets related to the research topic may prove to be challenging because the topic area is complex and that the results are frequently context dependent (Cleland & Durning, 2015). The research design involved using a descriptive cross-sectional survey approach, which included open-ended questions to facilitate the interpretivist enquiry about the research topic.

A descriptive cross-sectional survey research design is an inexpensive and efficient approach to capture a large quantum of data about a population at one point in time (Barnett, Mercer, Norbury, Watt, Wyke, & Guthrie, 2012; Setia, 2016). Descriptive cross-sectional survey studies assess the prevalence of the target behaviours or attitudes within a known population. Therefore,

one use of this research method is to capture baseline data about a population (Barnett et al., 2012; Setia, 2016). Descriptive cross-sectional survey studies do not enable causal relationships to be derived from the data (Barnett et al., 2012; Setia, 2016). However, this limitation was not considered to be important for this project.

Using an online survey was strategically important for this study. This is because Australia is geographically large, spanning 7,656,127 square kilometres (Australian Government, 2018). Using an online survey enabled the participation of different groups within the Australian sonography profession – for example, general, vascular and cardiac sonographers. Furthermore, when a census sampling approach is used, all sonographers located across the continent have the same opportunity to participate in the study (Kumar, 2011; Sarantakos, 2013). This strategy was important to minimise response bias which may have been encountered by using other sampling approaches (Sarantakos, 2013). The main limitation of using a survey as the research method is that it relies on the credibility (Evans & Mathur, 2018) and the accuracy of the self-reported data (Creswell, 2008; Molloy, 2009).

Other data collection methods which could have been used to discover the knowledge related to this research topic included using interviews and direct observations of the health professionals clinical practice behaviours (Creswell, 2008; Molloy, 2009). The use of live video to observe the teaching practices of sonographers or alternatively, structured or semi-structured interviews (Sarantakos, 2013) presented several and impractical methodological limitations. For example, both data collection methods would have provided unintentionally biased data and insufficient data about the teaching approaches used by the profession. This is because this research method would have required convenience sampling (Kumar, 2011); consequently, the collected data and results may not be representative of the broader professional population (Creswell, 2008). Using research methods which result in data being collected from small sample numbers has research implications and limits the consistency, relevance, and real-world application of the data (Kumar, 2011; Sarantakos, 2013). Therefore, using a cross-sectional research survey approach (Sarantakos, 2013) and a census sampling approach allowed data to be collected from a diverse cohort of Australian sonographers who perform a range of clinical examinations in both public and private practice. The decision to use this approach was influenced by many factors, which included:

1. The research question was focussed on determining the skill-teaching behaviours and perceptions of a professional cohort of sonographers in Australia.

2. There was anecdotal evidence that Australian sonographers used a two-step and/or master-apprentice skill-teaching approach to teach scanning skills and this assertion had not yet been empirically substantiated.

3. The survey could be administered electronically and therefore reach all sonographers located across the states and territories of Australia.

4. The professional cohort had internet access and were computer literate.

5. The research method could be replicated if required.

Using an online survey and a census sampling approach would maximise the potential for garnering a large enough sample of data from the professional cohort. A sample number of at least 350 participants was required (Creswell, 2008, p. 156) to ensure the collected data is accurate and representative of the population.

A survey instrument is not limited to using either a quantitative or qualitative research methodology; frequently, both research approaches can be used within the one study. While a cross-sectional survey design approach is often used to collect quantitative data, the inclusion of questions with open text responses does enable qualitative data to be captured about the research area which may not yet be known or requires further clarification (Creswell, 2008). The inclusion of this question format was intentional in the survey instrument to provide insights and perspectives about the research topic that may not have otherwise become known (Sarantakos, 2013). The responses to the open text questions were analysed using content analysis (Saldana, 2009; Green & Thorogood, 2018). The purpose of performing content analysis in this research project was to identify the knowledge and key concepts about the factors which influenced the sonographer's approaches used to teaching scanning or psychomotor skills. The use of open text questions may also identify heuristic teaching approaches used by the profession. The results of the descriptive statistics analysis provided the data about the key concepts and domains related to the research question. They enable large data sets to be condensed and summarised as percentages and explored for variations and trends (Creswell, 2008).

A review of grey and published literature failed to identify an instrument which could be used for this research topic. Consequently, a survey instrument was purposefully developed to explore the key concepts and domains related to teaching a complex psychomotor skill. However, there were

no professional publications in the field of medical ultrasound which could be used as a guide to develop and validate the instrument. Therefore, the nine-step approach suggested by Sarantakos (2013) was used to guide the development and validation of an instrument. These nine steps are tabulated and described in detail in the following chapter. To commence this body of research, the key theoretical concepts related to teaching a psychomotor skill were identified. Next, the relationship and interconnectedness of the key concepts and theory to teach a complex psychomotor skill were reviewed, analysed, and then mapped. The relationships between the key concepts are schematically depicted in Figure 7.1.

Motor Learning Theory and Principles: guide the pedagogical steps to teach a psychomotor skill

Assumptions: all motor actions to execute the skill are visible when the psychomotor skill is being demonstrated

Skill-Teaching Models: various models to teach psychomotor skills 2 -11 steps.

Teaching a psychomotor skill

Miller's pyramid: stages associated with acquiring a psychomotor skill are different for each learner

Skill Categorisation: simple or complex - differing teaching approaches required

History of US in Australia: master-apprentice skill-teaching approach

Figure 7.1: The theory and concepts related to teaching a complex psychomotor skill; for example, scanning, or psychomotor, skills

The concepts which are related and relevant to the research topic included:

1. A psychomotor skill can be categorised as being complex or simple (Wulf & Shea, 2002). The skill should be categorised before it is taught. This is because different pedagogical approaches are required to teach and learn each skill category. A review of the educational tenets related to teaching simple and complex skills were outlined and described in Chapters 3 and 4.

2. There are enduring and established motor-learning theories which underpin the pedagogical approaches suggested to be used to teach psychomotor skills (Simpson, 1966; Fitts & Posner, 1967; Gentile, 1972; Harrow, 1972) and in particular complex psychomotor skills (Wulf & Shea, 2002; van Merriënboer et al., 2006). These theories and principles were reviewed in Chapter 4.

3. The history of the development of ultrasound as an imaging modality in Australia (Hassal, 2007) has been a potent influence on the way psychomotor scanning skills are currently taught. This is because the pioneers of the profession were self-taught and learned the psychomotor scanning skills required to use the ultrasound machines on the job. They then taught other operators the knowledge and skills to perform and interpret an ultrasound examination (Hewlett, 2018; Davies, 2018a). Therefore, pioneers of the profession have reportedly used a master-apprentice or two-step skill-teaching approach to teach the psychomotor scanning skills required for clinical practice. However, there may also be novel and heuristic pedagogical approaches that are being used by the sonographers and as discussed in Chapter 1, there is no research or published knowledge of these teaching practices.

4. Psychomotor skills can be taught using a range of skill-teaching models. These models use a varying number (ranging from two to 11) of instructional steps to teach a psychomotor skill (Walker & Peyton, 1998; George & Doto, 2001; Raman & Donnon, 2008; Orde et al., 2010; Nicholls et al., 2016a). In Chapter 4, an 11-step model is presented as one pedagogical approach to use to teach complex psychomotor scanning skills.

5. The goal of performing a skill demonstration for a psychomotor skill is so the learner can observe the sequence and magnitude of the motor actions or movements that are required to perform the skill (Spittle, 2013; Schmidt et al., 2019). However, when the psychomotor skill involves very small movements of the fingers and hand, these movements may not be made apparent to the learner through skill demonstration alone. Therefore, there is an

assumption that all motor movements are seen and perceived at the time of the skill demonstration.

6. The purpose of teaching and learning a psychomotor skill is to progressively scaffold, or progress, the learner's cognition and procedural knowledge of the psychomotor skill. Miller's pyramid (see Figure 7.2) illustrates the cognitive and procedural stages that are linked with a learner acquiring the theory and skills to perform and master a psychomotor skill (Miller, 1990, p. S63). The learner transitions through four stages to be able to perform a psychomotor skill. In Figure 7.2, the diagram depicts four discrete stages to learning and mastering a psychomotor skill. However, for the majority of learners the rate of skill acquisition and advancement is not defined into stages, is not continuous, and is not at a uniform rate (Spittle, 2013). Nevertheless, the diagram does correctly represent that psychomotor skills are acquired in stages and each stage is prerequisite to advancing to the next. The first stage involves the learner gaining the knowledge of the theory related to performing the skill, also referred to as "knows". The second stage of "knows how" requires the learner to observe the skill demonstration to gain an understanding of the sequence of the skill steps and the movements that are needed to perform the skill. The third stage of "shows how" involves the learner practising the skill and replicating the demonstrated psychomotor skill movements. The next step of "does" is contingent upon the learner intentionally practising the skill. With ongoing skill practice the skill begins to be performed without thinking about the skills steps. At this time, other tasks that accompany the skill, for example talking to the patient, can be attended to.

7. Dent, Harden, and Hunt (2017) argue that with varied and diligent practice the learner progresses final stage of "mastery". At this stage psychomotor skills are executed automatically and can be modified when required.
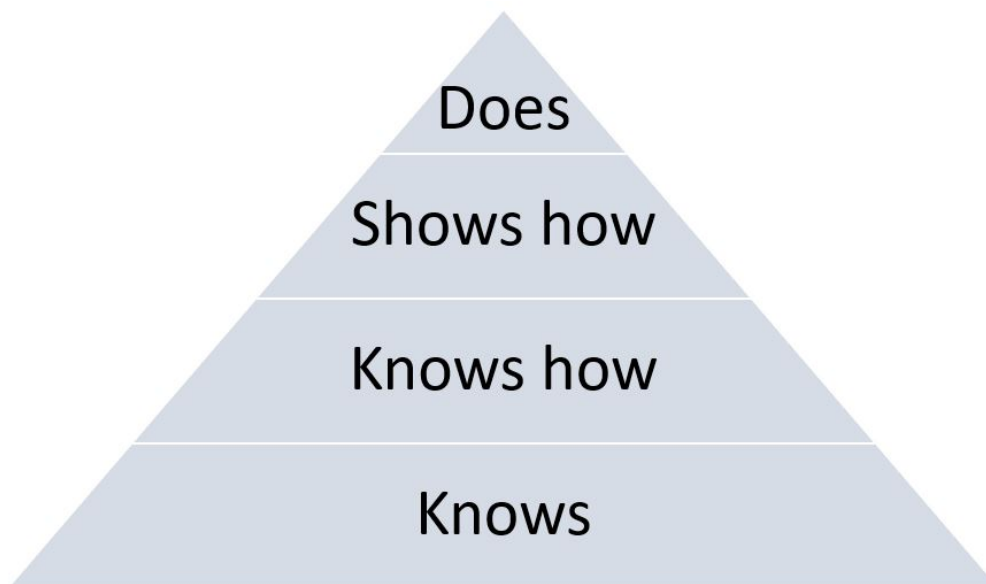
Figure 7.2: Miller's pyramid depicting the stages associated with learning a psychomotor skill
Source: Miller, 1990, p. S63.

Miller (1990) proposes in the four-stage model in Figure 7.2, that the learner must first have cognition of the theory related to performing the skill, e.g. this knowledge is antecedent to knowing how to perform the skill. It is not until the learner knows the combination and magnitude of the motor movements that they gain an understanding of the psychomotor movements to be able to attempt replication of the psychomotor skill. The skill is practised until the skill steps are smoothly and seamlessly executed with the correct timing and sequencing. At this point, the learner has developed a schema for the skill at it can now be recalled and modified as required (Kantak & Winstein, 2012). Mastery involves being able to perform the skill in a range of clinical situations and being able to correctly adapt the skill for each clinical scenario (Schmidt et al., 2019).

7.3   The Progressive Development and Application of the SonoSTePs Instrument

A search of the literature failed to identify a developed and validated instrument to use as a measurement tool. Therefore, the sonographer skill-teaching practices survey, named SonoSTePs, was purposefully designed and partially developed to explore the domains or themes related to teaching a psychomotor skill. The survey was designed after conducting a literature review and then subjecting the draft tool to the process of content and face validation. The instrument items were refined and changed after each stage of development. The timeline and steps to develop the instrument are represented in Figure 7.3. The development of the survey instrument proceeded

through three major stages. Stage one involved the development and initial validation of the instrument. At this stage the instrument proceeded through two expert panel reviews and was then pilot tested twice, referred to as pilot one (P1) and pilot two (P2), by a convenience sample of Australian educators and academics. Chapter 8 reports on the first stage of the SonoSTePs development. Stage two was concerned with performing the third pilot testing of the instrument. This stage determined the psychometric properties of the SonoSTePs instrument and established the test-retest reliability of the instrument. The focus of stage two was to determine the validity of the content domains of the instrument items and to determine the scales latent factors or domains through exploratory factor analysis. Chapter 9 describes the ongoing development of the instrument and the rationale for the further changes made to the instrument. Chapter 10 reviews the methodology used to undertake the national cohort survey study and performing statistical analysis to determine the instructional practices that were being used by Australian sonographers. The psychometric properties of the SonoSTePs instrument were defined using a larger sample number. This final stage excluded those sonographers located in Queensland as they had previously been sampled to establish the validation properties of the SonoSTePs measurement tool.
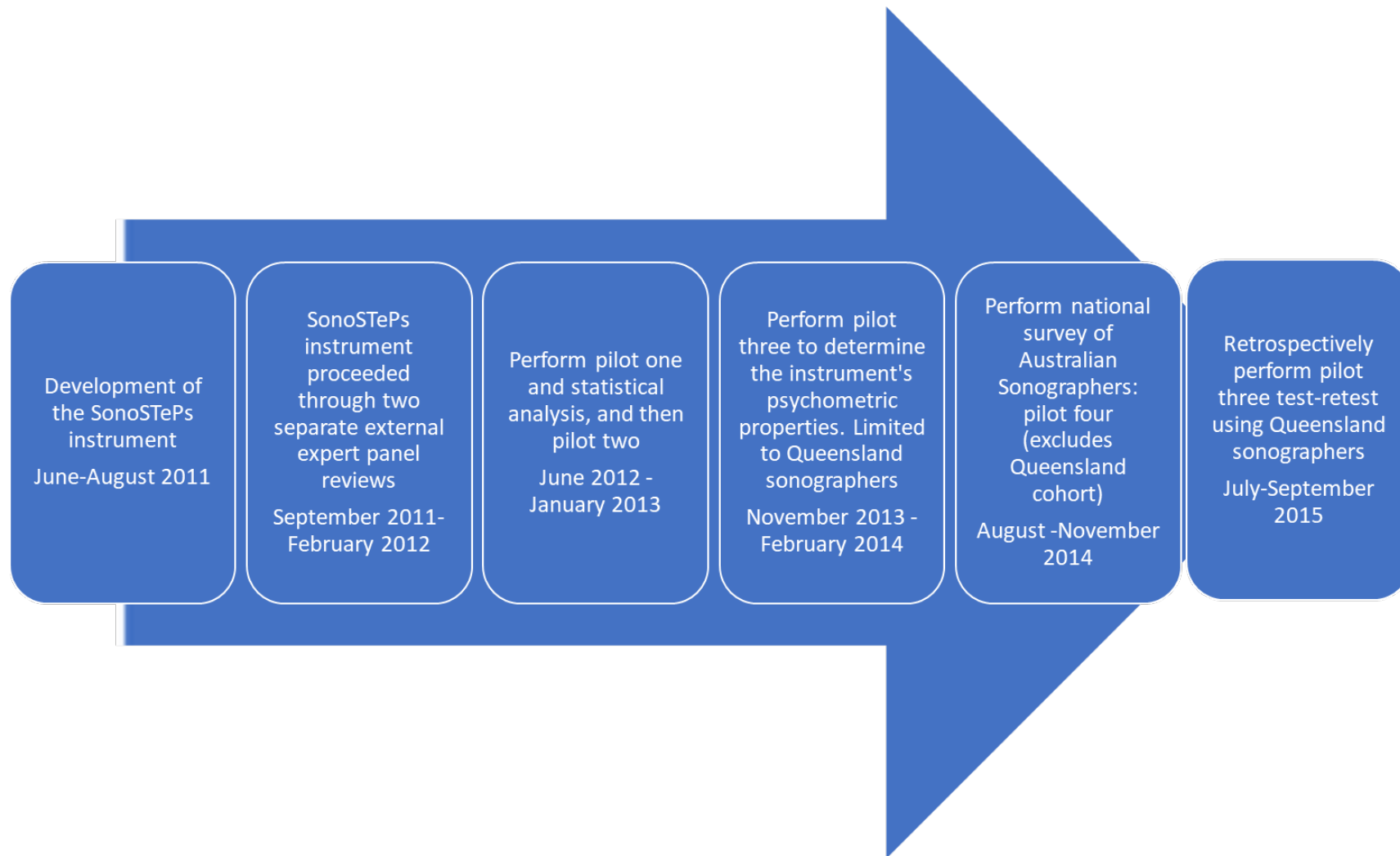
Figure 7.3: Timeline of research events spanning 2011 to 2015

7.3.1 Population and sampling approach

The population of participants to be surveyed were qualified sonographers. For the first three pilot tests of the instrument, purposive sampling strategies were used and the rationale for using this approach has been described in publications detailed in Chapter 8 and 9 respectively. Whereas, a census sampling approach was used for the national SonoSTePs survey, to ensure data was collected from a large and representative sample of the population. The rationale for using this approach is described in Chapter 10.

Qualified sonographers registered with the ASAR were contacted by email and invited to anonymously participate in the research. The decision to approach the ASAR to circulate the survey was made for three reasons:

1. It was a legislated requirement that all qualified sonographers practicing in Australia and claiming Medicare rebates were registered with the ASAR. Therefore, they had an almost complete listing of sonographers in Australia.
2. The ASAR is the only governing body with a database in Australia that contains the professional records and contact details of all the sonographers registered to perform ultrasound in Australia. Sonographers on the data base can choose to "opt in" to receive professional electronic communication and this cohort was invited to participate in the research.
3. In contrast not all practicing sonographers are financial members of the ASA and ASUM. Therefore, to use either of these professional organisation's data bases, to circulate the email invitation, would have knowingly introduced response bias and potentially skewed the data and this outcome should be avoided (Kumar, 2011).

7.3.2 Survey administration

The anonymous self-administered questionnaire was emailed to qualified sonographers who had identified to the ASAR that they wished to be involved in professional research. The survey was administered electronically using SurveyMonkey software (www.surveymonkey.com), an internet based survey tool for questionnaire administration and collection of responses.

7.3.3 Ethics

The study was approved by the Social and Behavioural Research Ethics Committee at Flinders University, Adelaide, Australia (SBREC project number 5584). All potential participants were

provided an information sheet and consent on the opening page of the online survey, providing the voluntary choice of whether to continue or not. All data collected was anonymous.

7.3.4 Data entry and analysis

All results were downloaded from http://www.surveymonkey.com/website onto a Microsoft Excel spreadsheet and then imported into SPSS version 25 (IBM, Armonk, NY, USA) for descriptive and comparative statistical analysis. A range of statistical calculations were performed as the instrument proceeded through its development and validation and they are described in detail in the following chapters. A probability value of less than 0.05 was considered statistically significant.

7.4 Summary

This chapter has provided a broad overview of the research design and methodology used to explore how Australian sonographers teach scanning or psychomotor skills required for clinical practice. A purposefully designed survey instrument, labelled SonoSTePs, was developed and validated to use as the measurement tool for this study. The development of a survey instrument that captures accurate, relevant, and meaningful data is an iterative process. The stages of development and validation are described in the next three chapters.

8   STAGE ONE: THE DEVELOPMENT OF THE SONOSTEPS INSTRUMENT

8.1   Introduction

Following the decision to use a survey instrument as the measurement tool for this project, a search of published literature was conducted to find an existing instrument, and none were identified. Therefore, the sonographer skill-teaching practices survey, labelled SonoSTePs, was conceived and developed. The purpose of this chapter is to outline, discuss, and describe the methodological and statistical approaches that were used to develop and validate the SonoSTePs instrument. It is the first of three chapters dedicated to outlining the: initial and ongoing development and validation of the instrument; describe the challenges faced during the instrument development; and the need for further validation of the SonoSTePs measurement tool.

A survey instrument can collect a lot of data about a research area. However, to determine whether the tool collects reliable and valid data requires: (1) an evidence-based approach to be used to develop the instrument scales (Sarantakos, 2013; DeVellis, 2017), and (2) the instrument's psychometric properties to be quantified (DeVellis, 2017). At each stage of an instrument's development there are theoretical and qualitative steps that are required to ensure that the items and instrument domains or scales are clear, concise, and representative of the research area. Additionally, as the instrument proceeds through its development, there are specific simple analyses and more complex statistical analyses which are required to be performed. In particular, the complex statistics communicate information about the questions in the rating scales. The rating scale items are the banks of questions which are accompanied by a Likert or Likert-type response rating scale. Therefore, when an instrument contains other questions that are important to the research topic, it is important that the instrument's content is assessed as a whole and is subjected to peer review and academic scrutiny. Performing this step is particularly important when inaugural research is being undertaken. It is essential that items contained in the rating scale and elsewhere in the instrument are representative of the depth and breadth of the research area (Sarantakos, 2013). The following peer-reviewed paper describes the steps used to initially develop and validate the SonoSTePs instrument. The paper draws upon contemporary and seminal literature to guide the development and validation of the survey tool. A seminal body of enduring work published by Lynn (1986), from the nursing profession, has been used to support the theoretical and statistical development of the instrument. The antiquity of this reference is

acknowledged; however, this author's work continues to be cited in health professional literature related to survey psychometrics.

The following text was published in the peer-reviewed article listed below.

Nicholls, D; Sweet, L; Muller, A; Skuza, P; Hyett, J. Sonographer skill teaching practices survey: Development and initial validation of a survey instrument. *Australasian Journal of Ultrasound in Medicine*. 2016; 19(3): 109-117. *Citations (3).*

8.2 Sonographer Skill Teaching Practices Survey: Development and Initial Validation of a Survey Instrument

Following the decision to use a survey instrument for this project a search of published literature failed to identify a developed instrument to use as a measurement tool. Therefore, the sonographer skill teaching practices survey tool was purposefully developed. This approach was taken to ensure that the survey instrument collected reliable and valid data. To have this clarity of purpose and the reassurance that the instrument was collecting data about the research topic required: (1) an evidenced based approach to be used to develop the instrument scales, and (2) the instruments psychometric properties to be quantified (DeVellis, 2017). The psychometric properties, in this context refer to the reliability and validity of the instrument and these concepts are further explained in the following peer reviewed publication. In addition to these quantitative psychometric statistics, there are other qualitative steps that are also required to ensure that the items and domains or scales of the instrument are clear, concise and representative of the research area. The following paper chronicles the qualitative and quantitative steps needed to initially develop a survey instrument which is purposed to be used to explore a niche research area or topic.

8.3 Abstract

8.3.1 Objective

To develop and validate a survey instrument that measures individual perceptions of sonographer skill teaching practices.

8.3.2 Method

Questions were developed around the theoretical constructs of teaching psychomotor skills. These were derived from the published literature describing the motor learning domain. Five constructs relating to sonographer skill teaching practices are identified: teaching a new skill, providing a visual exemplar, immediate correction of errors in performing the skill (whilst recognising the

impact of cognitive overload), and allowing the learner to practice the skill. The developed survey instrument underwent two cycles of expert review and pilot evaluation. Qualified sonographers and academics with niche expertise reviewed and established the instrument content validity.

8.3.3   Results

Fourteen sonographers completed the first pilot (P1) and 19 completed the second (P2). This process produced a 30-item instrument (P2) using a frequency seven-point Likert-type scale, resulting in good variation ratios (0.68 across 24 items; SD=0.11). Questions on the application of simulation to teach a skill were found to be required.

8.3.4   Conclusions

A survey instrument was produced to measure perceptions of sonographer skill teaching practices, labelled SonoSTePs, and it was assessed by experts in the fields of education, statistics, and ultrasound. The SonoSTePs survey (inclusive of sub-dimension on simulation) was found to have appropriate content and face validity. The frequency seven-point Likert-type scale was able to discriminate between individual participant's teaching practices. Small sample numbers preclude psychometric statistical analysis of this survey instrument, which will be the subject of future work.

8.4   Introduction

An ultrasound scan is a complex medical examination and sonographers need a diverse range of skills to both perform the scan and document their findings competently. The foundational skills required to physically perform and visually interpret the scan are termed psychomotor skills (Nicholls et al., 2014). These can be sub-divided into the categories of visuo-motor and visuo-spatial skills that enable the sonographer to manipulate the ultrasound transducer for image acquisition, whilst mentally constructing a three-dimensional spatial orientation of the anatomical structures (Nicholls et al., 2014).

Psychomotor skills are unique to each profession and are first taught then learned. As a result, a number of psychomotor skill teaching models have been proposed for multidisciplinary health professionals in various clinical situations (Fitts, 1962; Simpson, 1966; Poole, 1991; Walker & Peyton, 1998; George & Doto, 2001; Rose & Best, 2005; Raman & Donnon, 2008). Universally, these models teach psychomotor skills through a stepped approach (whether the skill is simple or complex). An important aspect of psychomotor skill instruction is that the teaching practices are

based upon principles aligned to the motor learning domain (Simpson, 1966; Fitts & Posner, 1967; Walker & Peyton, 1998; Wise & Willingham, 2009). There is no published data that defines best teaching practices or describes how sonographers teach psychomotor skills. To our knowledge there was no published and validated instrument to measure sonographer skill teaching practices. Therefore, it was identified that there was a need for a valid and reliable survey instrument which would provide information about sonographer skill teaching practices. As a result, a sonographer skill teaching practices survey (SonoSTePs) was developed using published principles of questionnaire development and construction (Hamdorf & Hall, 2000; Sarantakos, 2005; Creswell, 2008; Schaeffer & Dykema, 2011; Johnson & Christensen, 2012).

This paper reports on the development and initial validation of SonoSTePs. The aims of the paper are to: (a) describe the conceptual framework and development process of the web-based SonoSTePs survey instrument, (b) report on the iterative process used to validate the content of the survey instrument, and (c) describe salient and relevant technical difficulties which arose during the validation process.

8.4.1   Materials and methods

8.4.1.1   *Development of the SonoSTePs instrument*

The SonoSTePs survey instrument was developed following general guidelines for scale development established by De Vellis (2012) and in particular using the nine-step approach to guide survey construction and design by Sarantakos (2013) (see Table 8.1). This model was selected to guide the questionnaire design and construction as it was systematic, logical, and able to provide safeguards to minimise major instrument design errors. This was an important consideration as there was very little research which had adopted this methodology and published the outcomes in the discipline of medical ultrasound imaging.

We note Sarantakos (2013) used the words pre-test or pilot test interchangeably. For the purposes of this research and survey design, a pilot test is defined as an activity to test the sample frame, questions, research methods, and instruments (Schleyer & Forrest, 2012; Sarantakos, 2013).

Table 8.1: Steps in questionnaire construction, design and analysis

1. Preparation-select survey type and method of administration. Search for developed survey or commence construction
2. Construct the first draft – construct survey questions around research themes
3. Self-critique
4. External scrutiny – ensure the survey is reviewed by industry experts and modify questions as required
5. Re-examine and review – where major changes are required proceed to previous step and ensure instrument undergoes external scrutiny again
6. Pilot test or pre-test – a small sample is selected to check the suitability of the survey as a whole
7. Revision-changes may ensue from pilot test. Go back to step 4. Small changes can move to step 8
8. Second pilot test
9. Formulation of the final draft

Source: Sarantakos, 2013, pp. 254-255

The initial step to developing a survey instrument involved determining the concept being researched, followed by identifying the central themes, called content domains, to be measured. It was initially difficult to identify the content domains relevant to teaching psychomotor scanning skills due to a dearth of empirical data and published literature on the research topic. A review of literature from the psychomotor learning field and health disciplines that use psychomotor skill teaching models for clinical tasks (surgical medicine (Kovacs, 1997; Reznick, Regehr, MacRae, Martin, & McCulloch, 1997; Walker & Peyton, 1998; Hamdorf & Hall, 2000; Lake & Hamdorf, 2004; Grantcharov & Reznick, 2008), colonoscopy (Raman & Donnon, 2008), dentistry (Virdi & Sood, 2011), nursing (DeYoung, 2003; DeBourgh, 2011) and physiotherapy (Rose & Best, 2005) identified five domains relevant to teaching psychomotor (scanning) skills in medical ultrasound. These five domains include: teach a new skill, visual exemplar, cognitive overload, immediate error correction, and skill practice. Table 8.2 lists the five content domains (or scales), a brief description of each domain, the literature which assisted with defining the domain, and the type of survey questions used.

Table 8.2: Teaching psychomotor scanning skills in clinical practice: scales and items

Dimension	Domain/Scale	Scale description
Teaching a clinical skill	Teach new skill	The extent to which skill tutors execute skill teaching elements described by George and Doto (Fitts, 1962; Simpson, 1966; Fitts & Posner, 1967; George & Doto, 2001) SUB SCALE Recognition of prior learning. The extent to which tutor establishes learners prior cognitive and psychomotor knowledge on skill topic (Reznick, 1993; Rose & Best, 2005; Dent & Harden, 2009; Castanelli, 2009) SUB SCALE Simulation The extent to which tutor uses simulated patient or phantoms to teach part or whole task clinical scanning skills
	Cognitive Overload	The extent to which tutors limit the quantity of information taught in any one teaching session (Phipps et al., 2008; van Merrienboer & Sweller, 2010; Young et al., 2014) The extent to which tutor performs task analysis (deconstruction) prior to teaching the skill (Hamdorf & Hall, 2000; George & Doto, 2001; Sullivan et al., 2007; Phipps et al., 2008; Lammers et al., 2008; Castanelli, 2009; Razavi et al., 2010; Jabbour et al., 2011) The extent to which the tutor provides concurrent feedback during skill practice (Winstein, 1991; Winstein et al., 1994; Walsh et al., 2009; Kantak & Winstein, 2012)
	Visual Exemplar	The extent to which a tutor performs a silent skill demonstration to provide a visual standard of performance of skill execution (Kovacs, 1997; Bjork, 1997; DeYoung, 2003; Raman & Donnon, 2008; Lammers et al., 2008; Dent & Harden, 2009; Castanelli, 2009)
	Immediate skill error correction	The extent to which tutor corrects incorrectly performed skills as they occur(George & Doto, 2001)
	Skill practise	The extent to which the tutor provides deliberate and supported practise opportunities in short skill sessions (<60 minutes), rather than one long session, to practice skills with feedback on performance (Pendleton et al., 1984; Ericsson et al., 1993; Reznick, 1993; Reznick et al., 1997; DeBourgh, 2011)

The next step to developing the survey instrument entailed generating a pool of questions to explore and examine key aspects of each content domain. There are no fixed guidelines to the number of questions (items) required to represent each content domain in a survey, although, as a guideline, there should be enough questions to adequately represent the key dimensions(De Vellis, 2012). The majority of items were derived from literature through a process of identifying the theoretical and learning principles applicable to motor skill teaching (the supporting literature is listed in Table 8.2). Two standalone questions were also written to elaborate and explore specific student sonography skill teaching preferences identified from one paper by Sonaggera (2004). For example, when teaching novice sonographers, scanning skill participants were asked 'When teaching a beginning student, a new skill, do you scan the patient first and then follow with

the student scanning after you?' The survey instrument also required a mixture of ranked questions using rating or frequency scales, closed-end and open–end questions to gather both qualitative and quantitative data (Sarantakos, 2013). Open-end questions provided the opportunity to gather additional insights which may have been excluded by using only closed questions. Pilot one (P1) survey items were produced after culling redundant, poorly worded, and confusing questions from an initially large bank of questions (Lynn, 1986; De Vellis, 2012). Pilot one survey was comprised of a total of 27 items. Rating scale questions were used for three of the items. Questions 13, 14 and 16 contained 10 or less questions in each rating scale. The instrument was assembled and formatted into three key sections: (1) demographics, comprised of 13 questions, (2) psychomotor skill teaching practices and skill feedback, which contained three rating scale questions and five closed/open text questions, and (3) validation feedback, which included five questions. Demographic data were sought to ascertain if skill teaching approaches were influenced by individual sonographer's professional practice, educational level, and type of educational qualification achieved. For example, in question eight we asked 'What is the highest level of qualification in ultrasound you have completed?' as we were seeking to establish the participants ultrasound qualification and response options ranged from 'On the job training with Grandfather credentialing to' to 'PhD' and 'prefer not to answer' to provide those PhD credentialed sonographers with the option for anonymity. This was an important point, as some states and territories have one sonographer in each imaging speciality with PhD credentials. In question nine we asked, 'What is the highest level of qualification in clinical health education you have completed?' Response options ranged from none to PhD. Question 10 explored whether sonographers had completed day or half day workshops to assist their teaching roles. This question was necessary because a course such as 'train the trainer' is not recognised as a qualification, yet it is a valuable course to undertake when performing a teaching role. The question asked was 'Have you completed extra training in clinical health education, such as completing 'train the trainer' course or workshops/courses conducted at national conference?' with a response option yes or no, and if yes please specify. The mix of questions in pilot one were wide reaching to garner professional practice and credentialing information to explore if educational level impacted professional skill teaching practices and behaviours.

8.4.1.2 *Validation feedback*

Validation feedback was twice sought from both an external expert review panel (informed consent was sought from the review panel to publish their name and salutation see Appendix 2) and targeted sonographers who completed pilot questionnaires (Lynn, 1986; Wetzel, 2013). This

vital process facilitated the critical analyses of the instrument content, format, and domains throughout the developmental period (Lynn, 1986). Qualitative feedback was sought from all scrutineers on the survey questions and clarity, the representativeness of the questions in relation to the research question, the survey format, and the participant information sheet (De Vellis, 2012). Data were also collected on the time to complete the survey and any user interface or technical difficulties encountered. This information informed subsequent iterations of the instrument content and design.

8.4.1.3   *Recruitment and sampling*

Sonographer clinical tutors, academics, and health educators were initially invited to participate in the pilot 1 (P1) and pilot 2 (P2) testing. Two types of sampling were used. The first involved identifying target participants from university web sites (purposive sampling, Kumar, 2011; Sarantakos, 2013). The second involved contacting participants via email and then inviting them to forward the email invitation and hyperlink to other sonographer tutors or health educators who performed an academic or instruction role in their institution (snowball sampling Sarantakos, 2013). Initially, nine emails were sent to participants in each cohort and follow-up email invitations were distributed to each professional cohort (as per well-established recommendations by Raffi, Shaw, & Amer, 2012; Schleyer & Forrest, 2012) and follow-up email invitations were distributed to each professional cohort.

8.4.1.4   *Questionnaire administration*

A web-based electronic questionnaire was chosen as the method of administration. The SonoSTePs survey instrument was distributed via an email link to an online version in SurveyMonkey. There are well-known limitations of online data collections (Evans & Mathur, 2005; Buchanan & Hvizdak, 2009), but the benefits included national sonographer access, cost effectiveness, user-friendliness, and these outweighed the risk of poor response rates to online surveys (Kumar, 2011; Zheng, Fear, Chaffee, Zimmerman, Karls, Gatwood, Stevenson, & Pearlman, 2011; Schleyer & Forrest, 2012; Raffi et al., 2012).

8.4.1.5   *Ethics*

Ethical approval (SBREC 5584) from the Flinders University Social and Behavioural Research Ethics Committee was obtained prior to study commencement.

8.4.1.6 *Statistical analysis*

All results were downloaded from http://www.surveymonkey.com website onto an Excel spread sheet and then imported into SPSS (Statistical Package for Social Sciences, version 21.0.; IBM Corp., Armonk, NY, USA). Limited quantitative data analysis was performed due to small sample sizes in both pilot studies. The qualitative and quantitative data were analysed for descriptive and comparative data. Responses to open-ended questions were evaluated using content analysis (Saldana, 2009). This allowed the exploration of the feedback on the content, dimensions of enquiry, and usability of the instrument. Variation ratios were calculated for P1 and P2. According to Weisberg (2004), the ratio provides a measure of dispersion of participant responses across a scale for a given question. Ratio values can range from 0–1 (Weisberg, 2004). A ratio of 1 or close to 1 is desirable and indicates there is a broad range of responses across all categories for the question. Conversely, a ratio which approaches 0 indicates the scale was incapable of discriminating participant responses.

8.5 Results

Once developed, each version (P1 and P2) of the survey instrument, proceeded through, expert review consisting of four reviewers (Lynn, 1986; Wetzel, 2013), and pilot test (Sarantakos, 2013). This rigorous process was applied and undertaken to establish content and face validity of the instrument. Between each review and pilot test the questions, question order, Likert-rating scale, and content was modified based on data garnered from feedback from the expert review panel and pilot studies. The next sections will discuss the first and second pilots in more detail.

8.5.1 Pilot one (P1)

Over a 6-week period, eight survey responses were received after the initial email, and a further seven responses were received following a reminder email. One response was an empty entry. No educators from the discipline of clinical health education participated in the P1 pilot, despite being invited. The P1 demographic data revealed that 50% of all respondents were 50–59 years old, predominantly female (71%), with a large proportion employed as university lecturers (46%). Two participants had a PhD qualification in ultrasound and a further six had a master's qualification. Half of all participants had completed a formal qualification in clinical health education. The P1 survey used a 5-point scale to measure participants' attitudes to the research question in a format similar to a Likert scale (Creswell, 2008; Sarantakos, 2013; Kaye & Johnson, 2016). In Figure 8.1, the stacked bar chart frequency distribution for one 9 item rating scale question, exploring

sonographer teaching practice behaviours, illustrates the concentration of responses across two rating scales. The distribution of the responses to the 5-point scale, of attitudinal questions assessing sonographers' skills teaching and feedback practice, indicated a considerable clustering of responses for most of the questions (18 out of 24). For all these items, only two response categories accounted for over 80% of all pilot data available. Furthermore, four questions had a single category selected by over 90% participants. The average of variation ratio across all 24 items contained in the three rating scale questions was 0.38 (SD = 0.21), and this result indicates a limited variability and discrimination capability for P1 items. The 5-point scale was therefore modified to a 7-point scale as recommended by Vagias (2006). The subsequent P2 used a scale ranging from 1 (never) to 7 (always) for data collection (Beckstead, 2014). The qualitative survey feedback received at the P1 stage of the validation process focussed on survey flow and length, question clarity, and administration of the online survey tool. A descriptive content analysis of the qualitative feedback identified three categories. These were broadly grouped into user interface, technical issues with online survey, and survey content. Regarding user interface, one respondent replied, 'Would be good to have a completion bar % across top of survey so you know how far to go' and 'radio buttons instead of yes/no written responses'. Another respondent stated, 'I found the survey easy to navigate'. Respondents replied with contrasting feedback regarding sufficient room for open-ended questions. One respondent replied, 'sufficient room' while four replied 'could do with more room' and '...more space might be useful'. Two respondents gave feedback on the survey content. One respondent replied 'there is no assessment of skills. Maybe something could be included around the assessment/expectations of skill development for students' and another respondent suggested including content on simulated learning: '...It might have been appropriate initially to syphon off the lecturers into an extra feedback area for simulation teaching with some appropriate questions'. As a result of the P1 feedback, modifications were made to the explanatory letter to participants invited to participate in P2 validation process. Participants were advised that the survey was not exploring assessment of skill or competence. An optional three questions were included on the use and role of simulation to teach psychomotor scanning skills and this was added as a sub dimension to 'teach new skill'. Also, the expert panel identified the need for a definition of simulation and examples of simulated learning aids in order for participants to understand and answer the optional questions about the use of simulation to teach psychomotor scanning skills. Both Schaeffer and Dykema (2011), and Sarantakos (2013) highlight the need to define all technical terms to minimise poor or non-response bias when constructing questions for a survey. The P2 survey was modified to incorporate these three questions and

expert panel suggestions and these extended the instrument to 30 items. The rating scale items were reduced from 25 in P1 to 24 in P2 after the removal of a question exploring whether simulated aides were used to teach psychomotor skills. Four questions on this topic area would have been an excessive number.

The median time to complete the survey was 20 min, with a range of 10–75 min. An outlying value of 75 min was recorded as a result of encountering technical difficulties to complete the survey. Furthermore, another two participants reported technical errors which were corrected and did not impact the completion time.
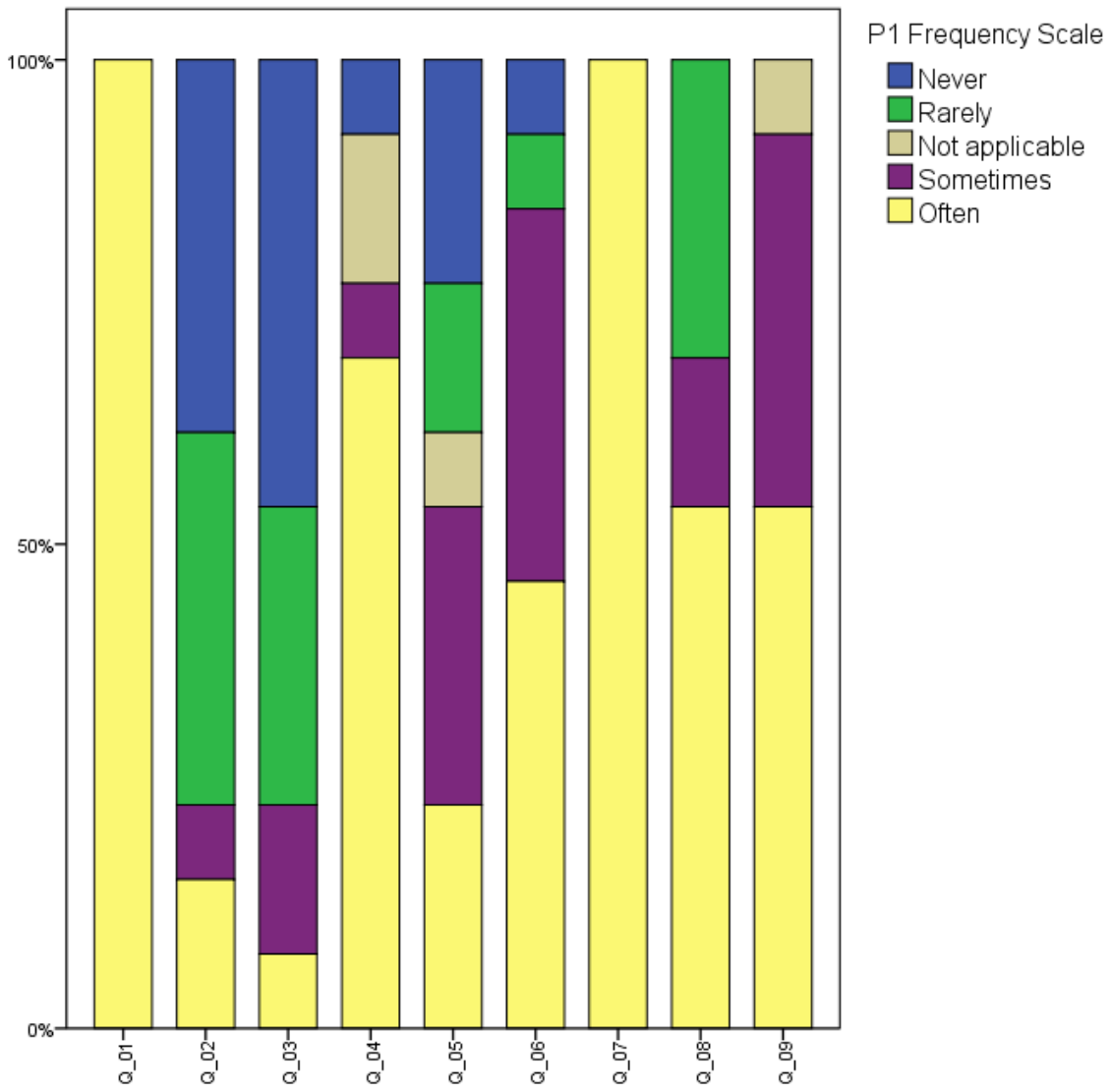
Figure 8.1: Stacked bar chart with responses to the questions related to teaching new skills from P1 pilot study which used Likert five-point rating scale (*n*=14)
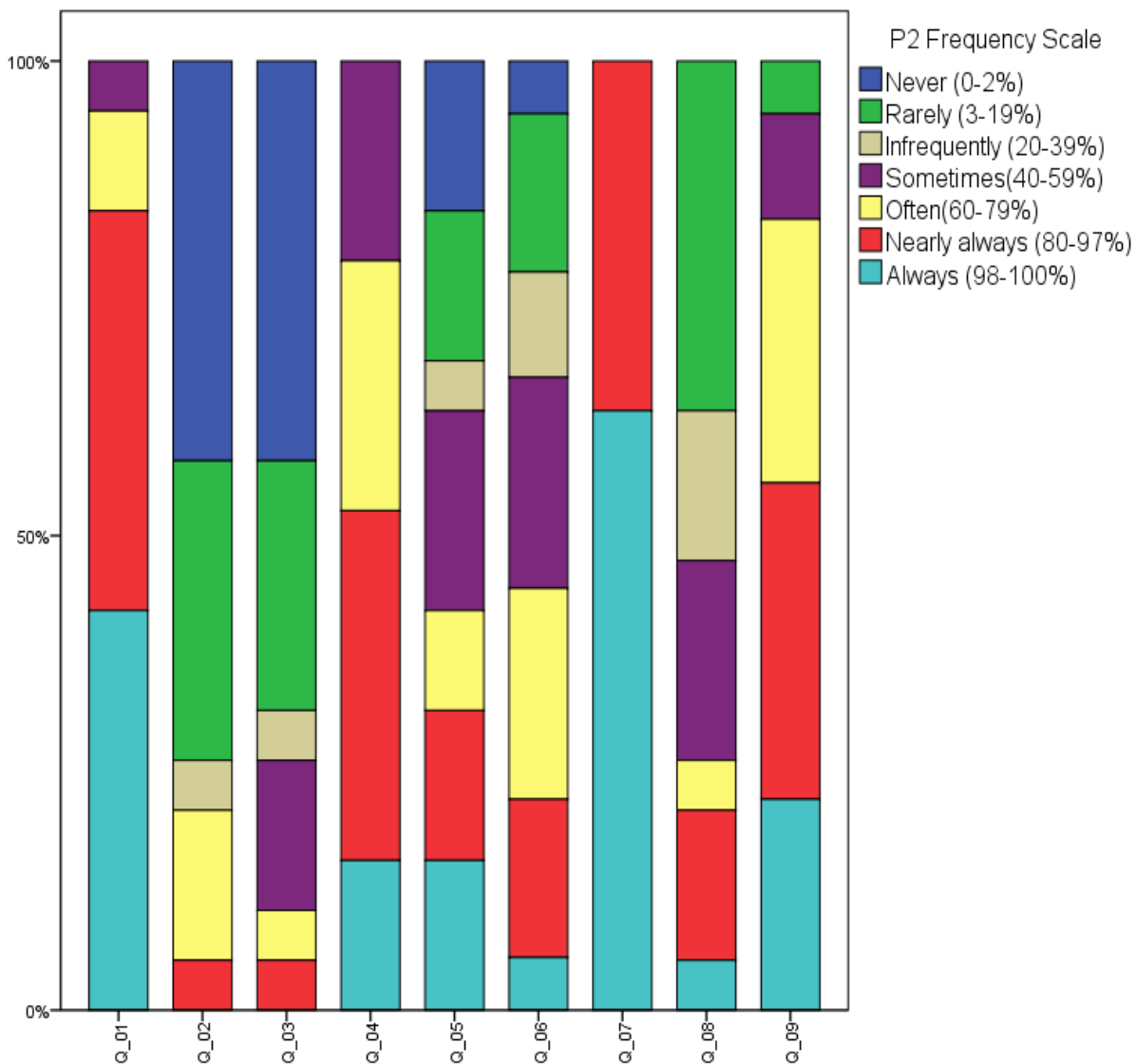
Figure 8.2: Stacked bar chart with responses to the questions related to teaching new skills from P2 pilot study which used Likert seven-point rating scale (*n*=19)

8.5.2 Pilot 2

Over an 8-week period, 14 survey responses were received after the initial email and a further five responses were received following a reminder email. Nineteen sonographers participated in the P2 validation of the survey. No educators from the discipline of clinical health education participated; despite being invited. Analysis of the demographic information showed that almost half of participants were over 50 years old, with 84% of them being females. The most represented group, in regard to professional role, were clinical sonographers (37%). The majority of the cohort (61%) was employed as general sonographers in public hospitals. One-third had completed an additional clinical health qualification. The 5-point scale used in P1 survey (see Figure 8.1 for distribution of responses) was adjusted to a seven-point frequency scale (never-always) rating scale in P2 (see Figure 8.2 for the distribution of participant responses using a

seven-point frequency scale). In order to acquire more meaningful data regarding sonographer teaching practices and behaviours frequency adverbs (Leitz, 2009, p. 255) were accompanied by a frequency per cent range (never: 0–2% of time, rarely: 3–19% of time). These strategies we hypothesised would overcome both the described limitations using the 5- point scale, and the potential ambiguity of using word responses which according to Dillman, Smyth, and Christian (2014) means something different to each participant. The average variation ratio across the 24 items contained in the three rating scale questions was 0.68 (SD = 0.11) and this indicates that the discrimination capability of items from the P2 scale has improved. In Figure 8.2, the P2 frequency distribution for the same 9-item rating scale question, using a 7-point scale illustrates a dispersion of responses across all rating scales. The content analysis of the qualitative survey feedback received in the P2 validation process identified two categories. These are broadly grouped into question clarity and technical issues with online survey. Two respondents had difficulty interpreting one of the questions containing more than one variable. Kumar (2011, p. 154) explains that an ambiguous question is 'one that contains more than one meaning and that can be interpreted differently by different respondents. This question has since been reviewed and rewritten. All respondents identified that there was enough room to complete the open text questions. The time to complete the survey ranged from 10 to 30 min with the median value being 15 min. Similar to the P1 pilot, two participants' experienced technical difficulties, which were dealt with promptly.

8.6 **Discussion**

The aim of our research was to undertake initial development and validation of a survey instrument which would be capable of identifying and measuring sonographer skill teaching practices. The survey instrument development and validation model published by Sarantakos (2013) provided a framework with which to guide construction and survey content. Applying these steps resulted in the instrument proceeding through two pilot tests and expert review. The results of both pilot tests allowed the development of a measurement instrument, labelled Sonographer Skill Teaching Practices Survey (SSTPS) and subsequently named SonoSTePs. There are a few main points worth mentioning in this discussion, as will be seen in the comments in the following sections on demographics, expert panel review, refining the survey content, and Likert rating versus frequency scale.

8.6.1 Demographics

The demographic profile of the pilot cohorts completing the survey indicated their adequate representativeness of the broader profession in Australia, which is female dominant. Currently, the female–male ratio of practicing sonographers is 3:1. The Australian Sonography Accreditation Registry (ASAR) reported the in 2012 there were 3380 (76%) females sonographers and 1080 (24%) male sonographers (ASAR 2014b). Our study data demonstrated similar female/male percentages, P1 (71% and 19%) and P2 (84% and 16%). Furthermore, of the academic sonographer cohort, approximately 50% of the P1 and 67% of the P2 cohort had completed additional qualification in clinical health education; therefore, we hypothesise this cohort had the expertise to review the survey content (Creswell, 2008, p. 214). It is of note that only sonographers completed P1 and P2 surveys, although we had invited nine clinical health education academics with niche educational knowledge and expertise to review the instrument. This void was filled by the expertise of the expert review panel and we suggest was not detrimental to the development of the survey instrument.

8.6.2 Expert panel review

Both Lynn (1986) and Wetzel (2013) suggest at least three panel members are required to critically review the instrument content. We selected four panel members to review each pilot study and their comments lead to question restructuring, rewording, brevity, and placement within the survey. One expert panel member identified the necessity to include a definition of simulated learning in the P2 survey, while another identified the use a seven-point of frequency scale would assist with response discrimination.

8.6.3 Refining the survey content

The validation process involved the evaluation and analysis of the five content domains and the appropriateness of the rating or frequency type-Likert scale in P1 and P2. As a result of the iterative process to validate the content domains of the survey, the survey was revised. A further subgroup of 'teach new skill' was modified to incorporate a section on the use of simulation to teach psychomotor scanning skills. The inclusion of these questions in the P2 survey meant the stand-alone rating scale question on simulated learning, was now redundant and removal resulted in 24 items. Anecdotally, simulation is widely used in medical ultrasound imaging in Australia to teach foundational psychomotor scanning skills. However, at the time of the survey instrument's development (2012), a paucity of profession-specific literature made the exploration of the sub-theme difficult. The use of current and representative content domains is a crucial step in the

development of a validated survey instrument. Ensuring the instrument authentically and wholly represents the concept being explored and measured is an important step towards establishing content validity. Content validity is reported by Lynn (1986, p. 382) in seminal literature as "the determination of the content representativeness or content relevance of the elements/items of an instrument...". Polit and Beck (2006, p. 489) additionally highlight the need for an instrument to have 'an appropriate sample of items for the construct being measured'. Both Lynn (1986) and Polit and Beck (2006) concur that a research instrument must be assessed for content validity prior to use. P1 and P2 were an attempt to achieve this aim.

8.6.4 Likert rating versus frequency scale

Dillman et al. (2014) explain that a 5-point scale using a Likert design is one method to measure participants' attitudes, opinions, and behaviours to a research question. The P1 survey used a 5-point scale ranging from 1 (strongly agree) to 5 (strongly disagree), or 1 (often) to 5 (never). Participants were able to select not applicable (N/A). This option was located between rarely and often and had the potential for ambiguous interpretation by respondents. This was a design error and corrected in the P2 pilot. The responses to the 7-point frequency scale ranging from 1 (never) to 7 (always) for questions related to general skill teaching practices were plotted into a stacked bar chart (see Figure 8.2). The frequency responses of skill teaching and feedback practices exhibit a broader distribution across all response categories when compared to the questions used in the 5-point scale in P1. The average of the variation ratios across all 24 P2 items was 0.68 (SD = 0.11). While it is acknowledged that a direct comparison between the average variation ratios from P2 and P1 cannot be undertaken (given that the wording of some items has changed and pilot samples are small and differ in regard to some of the demographic characteristics), it can be argued that items from P2 are more variable. The decision to use a 7-point frequency scale with unequal anchor points was based upon two factors. First, the 5-point scale used in the P1 was deemed incapable of satisfactorily discriminating frequency responses across categories. Second, the results of P2 pilot analyses, as well as the literature, support the use of a 7-point frequency scale as having the ability to discriminate more efficiently (Streiner & Norman, 2008). This use of a quantified frequency scale was an attempt to glean nuanced perceptions of skill teaching practices. Indeed, it seems that this aim was achieved. Unlike the 5-point scale in P1, the participants' responses to perceptions of skill teaching practices were dispersed across the seven rating scales in the P2 7-point frequency scale (see Figure 8.2) (Streiner & Norman, 2008). Technical difficulties were encountered while using the web-based survey instrument. The errors

were corrected through email correspondence quickly after the initial survey was dispersed (Raffi et al., 2012). Undertaking a small pre-test of the instrument prior to commencing pilot testing would have revealed these programming errors (Kumar, 2011, p. 266; Sarantakos, 2013). Schleyer and Forrest (2012, p. 419) identify that one purpose of a small pre-test is to test the user interface, usability of the instrument, and detect programming errors prior to distribution of the instrument.

8.7   Limitations

Due to the nature of pilot studies, the small sample sizes of P1 and P2 limited the possibility of more formal statistical assessment of changes to the item's variability between P1 and P2, although the demographic characteristics of both P1 and P2 samples were relatively comparable. As a result, the utility of the survey instrument will need further testing and refinement on a larger population.

8.8   Summary

The P2 survey instrument evolved from a 27-item to a 30- item questionnaire. Between P1 and P2, the survey content and Likert scales were changed, and this improved the dispersion and distribution of responses to probing teaching practice questions. Further research is required to perform basic exploratory psychometric statistical analysis of the measurement instrument using a sample number of at least 300 participants (De Vellis, 2012). These processes are critical to the development of a robust instrument which is able to withstand critical review of instrument content, item clarity, and relevance (De Vellis, 2012). To avoid the program and access errors encountered with web-based surveys, we suggest performing a survey instrument pre-test prior to dispersal, to mitigate user interface errors (Schleyer & Forrest, 2012).

8.9   Acknowledgements

We thank members of the expert review panel: Marilyn Baird PhD; Linda Sweet PhD; Sue Campbell-Westerway PhD and Ann Quinton PhD for their assistance with the external review of the survey instrument see Appendix 2.

8.10   Summary

This chapter has provided an overview of the methodological and statistical steps used to develop the SonoSTePs instrument. The survey tool construction and development were guided by the nine-step approach proposed by Sarantakos (2013) and the published principles of survey

development outlined by DeVellis (2017). It was important to follow these published guidelines of survey construction and development. This is because there was no published profession specific literature which could be used to inform the instrument development or the statistical analysis required to create a reliable and valid measurement tool. To ensure that the instrument items were representative of the depth and breadth of the research topic, and that the Likert rating scale provided appropriate discriminant ability, the survey instrument progressed through two sequential pilot assessments. Between each pilot, P1 and P2, further changes were made to the SonoSTePs instrument. First, the rating scale items were refined and improved. Second, further questions were added to the item pool on the role of simulative aides. Last, the Likert rating scale was changed from a 5-point to a 7-point scale to improve the discriminant ability of the frequency scale. Following these changes, the P2 instrument contained 30 items and three questions contained a total of 24 rating scale items. The next chapter chronicles the steps required to further develop and validate the SonoSTePs instrument.

9 STAGE TWO: CONTINUING DEVELOPMENT AND INITIAL VALIDATION OF A QUESTIONNAIRE TO MEASURE SONOGRAPHER SKILL-TEACHING PERCEPTIONS IN CLINICAL PRACTICE

This chapter outlines the steps and rationale for undertaking the third pilot, referred to as pilot three (P3), of the SonoSTePs instrument. Between P2 and P3, further changes and refinements were made to the pool of rating scale items and this revision resulted in a net change of 5 items; consequently, the P3 instrument contained 25 items. The focus of this stage of the research was to advance the development of the instrument and to determine the psychometric, or statistical, properties of the tool. These parameters, when known, provide the metrics about the reliability, stability, and validity of the measurement tool (DeVellis, 2017). These numerical values provide information about the quality and the cohesion of the instrument items in regards to domains related to the research topic. Importantly, these metrics *only* relate to the instrument's questions contained in the rating scales. These statistics do not provide metrics and information about the other stand-alone items contained in the instrument; for example, the closed- and open-text questions about the use of simulation to teach psychomotor scanning skills. Therefore, the objective review and critique of the instrument items by industry experts during the initial development, and then the further pilot testing of the instrument was an essential step. Indeed, the development of this instrument was reliant upon the statistical analysis of the instrument's psychometric properties as well as the iterative analysis of the instrument by industry experts. Therefore, the development of a new survey relies on the qualitative assessment and the quantitative analysis of the instrument items. The outcome of both analyses is not mutually exclusive, and this is an important point to note during the development of a new measurement tool.

A large convenience sample of sonographers who performed ultrasound examinations in one Australian state or territory was required to perform the third pilot test of the instrument. It was important to be able to isolate this cohort from the national group of sonographers. This is because once these participants completed the survey they could not be resampled (Creswell, 2008; Sarantakos, 2013). Therefore, this cohort were excluded from the final group of qualified sonographers that were invited to undertake the national SonoSTePs survey. To further test the stability of the instrument a retrospective test-retest was performed on a small cohort.

The following peer-reviewed paper chronicles the steps and research methodology used to advance the developments and validation of the survey instrument.

Nicholls, D; Sweet, L; Muller, A; Hyett, J; Ullah, S. Continuing development and initial validation of a questionnaire to measure sonographer skill-teaching perceptions in clinical practice. *Journal of Medical Ultrasound*. 2017; 25: 82-89. *Citations (2).*

9.1   **Abstract**

9.1.1   Objective

Medical ultrasound examinations are performed by diverse professional cohorts; sonographers are one group. Operators need to be highly skilled to be able to produce trustworthy and accurate diagnostic results. There is little data and therefore knowledge of the instructional practices used to teach the co-ordinated and complex psychomotor skills required to perform an examination. We report the continued development and validation of an instrument to measure sonographer skill-teaching practice perceptions (SonoSTePs).

9.1.2   Method

The developed tool has progressed through generation of items, content validity testing, expert panel review, and Likert rating scale discriminant ability. An online survey consisting of demographics, professional practice, skill teaching approaches, and validation feedback was administered to a convenience census sample of sonographers and academics, who were employed in Queensland, Australia. This paper reports on the continued psychometric testing of the measurement tool.

9.1.3   Findings

The 25-item scale demonstrated good internal reliability. An evaluation of construct validity through exploratory factor analysis (EFA) generated four factors with acceptable internal reliability: Factor 1 (Skill execution feedback, Cronbach's alpha = 0.89), Factor 2 (Cognitive overload, Cronbach's alpha = 0.68), Factor 3 (Teach new skill, Cronbach's alpha = 0.70), and Factor 4 (Assist learners scanning, Cronbach's alpha = 0.67).The combined Cronbach's alpha for the instrument value was 0.83. Weighted kappa of the test-retest items identified the majority of items achieved an inter-rater level of agreement of 0.5 or greater.

9.1.4 Conclusion

Results indicate that the SonoSTePs instrument items and factors are underpinned by theories and principles related to teaching a complex psychomotor skill. Initial data suggests that the tool is both reliable and valid.

9.2   Background

Medical ultrasound is now a ubiquitous imaging modality, and is used by a diverse professional cohort, for a wide range of clinical applications and contexts. It is a salient point, that for more than 40 years, medical ultrasound imaging has been largely performed by sonographers and doctors, in established disciplines such as radiology, cardiology, vascular surgery, and obstetrics and gynaecology. In recent years, the clinical application of medical ultrasound in the health and education contexts has expanded. For example, rheumatologists, rather than solely relying on palpation of anatomy, use ultrasound imaging to guide targeted injections into tendons, bursa, and joints (D'Agostino & Schmidt, 2013). Similarly, midwives are using ultrasound imaging (Swanson et al., 2014) to determine fetal number, presentation, and placental location. This ultrasound information assists the clinical management of patients. Furthermore, medical students attending universities in the United States of America use ultrasound to assist cognition of anatomy and pathophysiology during their undergraduate education (Bahner et al., 2013; Bahner, Goldman, Way, Royall, & Liu, 2014). Nevertheless, the single largest cohort to use ultrasound imaging in a diagnostic and clinical capacity remains sonographers. Despite this, there is no literature that we could identify which outlines the instructional approaches used by sonographers to teach the basic psychomotor scanning skills required for competent clinical practice. Therefore, there is no knowledge of the teaching practices used by the educators in the profession and consequently they cannot be objectively reviewed, examined, and assessed.

Anecdotally, the ultrasound profession uses a master apprentice or two-step skill-teaching model (Archer et al., 2015) to guide the acquisition of essential psychomotor skills. The model relies on the sonographer educator demonstrating and describing the task steps to the learner. To date, this instructional model has served the profession well. However, contemporary skill-teaching and motor-learning domain literature has identified that additional instructional steps are needed when teaching multi-part and complex psychomotor skills (Nicholls et al., 2016a), where a skill must first be acquired, then performed, and lastly learned.

One method to measure sonographer skill-teaching practice perceptions is to use a validated survey instrument. A review of the literature failed to identify a suitable measurement tool for this purpose. Thus, the sonographer skill-teaching practices survey, labelled SonoSTePs, was developed to identify and measure the major skill-teaching practices and perceptions used by sonographers, who perform formal or informal clinical teaching and supervision roles. So far, the content and face validity of the SonoSTePs instrument has been established (Nicholls, Sweet, Skuza, Muller, & Hyett, 2016b). However, as identified from the literature review, the analytics of the theoretical principles and instructional behaviours required to teach a complex and multi-part psychomotor skill have not been determined. The five theoretical sub-scales related to the domain of teaching a psychomotor skill in the clinical health arena include: teach new skill, visual exemplar, cognitive overload, immediate error correction, and skill practice. The purposefully written items which explore the sub-scales related to teaching a psychomotor skill in the SonoSTePs instrument are yet to be validated, and therefore determine how accurately this newly developed scale will measure perceptions of skill-teaching practice.

The purpose of this paper is to report on the continued development and validation of the SonoSTePs instrument. In particular, this paper aims to: 1) determine the instrument's reliability (test/retest and Cronbach's alpha co-efficient), and 2) to report on the steps taken and outcomes of an exploratory factor analysis.

9.3   Method

9.3.1   Continued development of the SonoSTePs instrument

In 2012, we commenced development of the SonoSTePs instrument using published principles of survey design and construction (Lynn, 1986; Sarantakos, 2005; De Vellis, 2012) to measure the perceptions of sonographer skill-teaching practices. Over a 13-month period the questionnaire items were developed, reworded, revised, and some removed following two peer reviews and two pilot studies, pilot one (P1) followed by pilot two (P2). Between P1 and P2 the rating scale was changed from a five-point to a seven-point Likert-type rating scale. This modification improved the discriminant ability of the instrument (Nicholls et al., 2016b). After each pilot, the question number, items (content), sequencing and wording were modified and changed. Following P2 analysis, the instrument items were further evaluated for appropriateness, clarity, and representativeness (De Vellis, 2012). This process resulted in a revised and reworded survey known as SonoSTePs P3.

Between P2 and P3, six scale items were changed. Following P2 analysis and as a result of reviewing additional and new publications, four questions were added regarding the scale of "feedback" and one question was removed from this scale because the item was now considered redundant. A further question was added to the domain of "cognitive overload" to increase the representativeness of this scale within the instrument. Other questions within the rating scale were modified because of misrepresentative grammar and length. Also, refinements were made to three Likert-type rating scale lead-in questions to improve their clarity and comprehension. Finally, adjustments were made to the question order and placement to minimise the perception of survey fatigue.

This refined SonoSTePs P3 instrument has two primary components. The first consisted of 23 questions seeking demographic information, clinical practice roles and qualification, skill-teaching behaviours, use of simulation to teach psychomotor scanning skills and four validation feedback questions. The second component contained 28 items, which were reduced to 25 items for statistical analysis, exploring five theoretical domains related to teaching a psychomotor skill contained within a Likert-type rating scale.

9.3.2 Recruitment and sampling

The population targeted to receive the P3 survey included Queensland sonographers registered with the national and compulsory regulatory agency, the Australian Sonographer Accreditation Registry (ASAR). Schleyer & Forrest (2012) explain that it is important when targeting an online population that the validation cohort is representative of the broader professional population and possesses the skills to undertake the instrument validation. The targeted cohort was purposefully and strategically chosen to pilot test the instrument as this professional group was: 1) comprised of sonographers who worked in a range of geographically disparate locations (which included metropolitan, semi-rural, rural and geographically remote areas); 2) performed a wide range of clinical ultrasound examinations (general, breast, vascular, cardiac, paediatrics, obstetrics and gynaecology, and musculo-skeletal); and 3) executed a diverse portfolio of professional practice roles (clinical, academic and education roles). Therefore, the cohort possessed a variety of skills and expertise, and significantly included academics and clinical tutors employed at two universities.

9.3.3 Questionnaire dispersal and administration

The SonoSTePs P3 pre-test, test-retest, and P3 state-wide survey, were administered electronically using Survey Monkey software (www.surveymonkey.com), an internet based survey tool for questionnaire administration and data collection.

A pre-test was performed prior to dispersing the P3 survey. This was done to ensure the survey was operational with no access or progress issues (Johnson & Christensen, 2012; Nicholls et al., 2016b). The "dummy" responses were deleted from the data repository, to avoid contamination of the test-retest and P3 data.

A convenience sample of sonographers who resided in Queensland, Australia were invited to voluntarily participate in the test-retest surveys. Participants were emailed twice (18 days apart via a third party) with an invitation, introductory letter, and a link to follow to the on-line test and retest SonoSTePs P3 survey. To enable comparative data analysis for each respondent, at two time points, the last four digits of their home or mobile phone number was recorded on the test and retest survey.

In November 2013, staff working at the ASAR sent an introductory email and hyperlink to 835 Queensland sonographers, who were registered with ASAR and had "opted in" to receiving professional electronic communication. Sonographers were invited to voluntarily and anonymously participate in the validation of the online version of the P3 survey. Two reminders were sent: the first at seven weeks after the initial invitation (which included the Christmas and New Year period); and the second one four weeks later. Therefore, responses were collected over a 14-week period. No incentives were provided to participate in this research project.

9.4   Statistical Analysis

9.4.1 Descriptive statistics.

The P3 data was downloaded from http://www.surveymonkey.com/ website onto an Excel spread sheet and then imported into SPSS (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.) and StataCorp. 2015 (Stata Statistical Software: Release 14. College Station, TX: StataCorp LP) to perform data analysis. Descriptive statistics were used to describe the demographic characteristics of the cohort. Item correlation and parallel analysis was performed using StataCorp. 2015 (Stata Statistical Software: Release 14. College Station, TX: StataCorp LP).

9.4.2   Temporal stability.

The SonoSTePs P3 temporal stability was calculated using test-retest response data, and applying a weighted kappa (kw2) with quadratic weights for ordinal items (survey questions)(Cronbach, 1951; Efron & Tibshirani, 1986; Hume, Ball, & Salmon, 2006). This statistic measures the inter-rater agreement at two times points, usually 14 days apart (Nunnally, 1978; Pett, Lackey, & Sullivan, 2003).

9.4.3   Establishing the SonoSTePs item correlation, factor loading, and internal consistency

Questionnaire data suitability was assessed using Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity, where KMO and Bartlett's values above 0.5 were considered suitable for EFA (Tabachnick & Fidell 2007. Williams et al 2012). A multiple approach model for factor extraction was used consisting of principal component analysis (PCA), Kaiser's criterion (Eigenvalues >1.0), scree test and parallel analysis, to simplify and reduce the items into factors and then determine the number of factors to be retained (Tabachnick & Fidell, 2007). We used Cronbach's alpha to explore the strength of the relationship of each item to the factor (Tabachnick & Fidell, 2007). Oblique direct-oblim rotation was used to further simplify the factor structure (Williams, Onsman, & Brown, 2010).

9.5   Ethics

Ethics approval (SBREC 5584) for the P3 pre-test, test-retest, and state-wide survey of Pilot 3 was gained from the Flinders University Social and Behavioural Research Ethics Committee. Potential participants were informed by introductory letter that their participation was voluntary, and responses would be anonymous.

9.6   Results

9.6.1   Assessing the temporal stability of the SonoSTePs instrument

There were 11 respondents who completed both the test and retest surveys. The Kappa values ranged from 0.1 to 0.8, where k=1 and k=0 corresponds to perfect agreement and no inter-rater agreement respectively. The majority (52%) of the 25 SonoSTePs P3 items achieved an inter-rater level of agreement of 0.5 or greater. This suggests acceptable internal consistency (Pett et al., 2003) for the SonoSTePs instrument. However, the small sample number precludes unmerited reassurance.

9.6.2 SonoSTePs P3 survey

After the initial invitation, 35 sonographers responded to the survey. Raffi, Shaw, & Amer (2012) assert that the use of follow-up emails is a potent tool to increase the survey response rate. Therefore, two further email reminders were dispersed, and this resulted in an additional 74, followed by 33, responses respectively. A total of 142 of 835 sonographers responded to the P3 validation survey, giving a 17% response rate. Nineteen respondents did not complete the rating scale questions and these responses were removed from the P3 factor analysis data set.

Participants ranged in age from 25 to 66 years (mean 44.8 years) and 81% were female. The majority were employed in private practice (55%), followed by public hospital (35%), private hospital (8%) and 2% were employed in a university capacity. Regarding the area of sonographic practice, 55% performed general sonography, followed by cardiac (22%), obstetrics and gynaecology (9%), breast (7%), vascular (6%), and paediatric sonography (1%). The participants identified that their primary role was to scan patients (83%), function as a chief sonographer (11%), and performed an academic or clinical teaching/tutoring role (6%). Most participants had not completed additional health education training or qualification (78%). However, fourteen participants had completed either the "train the trainer" course or Certificate IV in Work Place Training and Assessment. Twenty-two participants (15.5%) reported that they had completed additional health education qualification. For example, 2 participants had completed a graduate certificate, followed by 17 (16%) a graduate diploma, 2 a master by coursework and 1 indicated that they would prefer not to answer the question.

9.6.3 Qualitative results

Qualitative survey feedback received at the P3 stage of the validation process was primarily focussed on question clarity and survey content. A descriptive content analysis of the qualitative feedback found that most respondents found the survey questions to be complete and not difficult to interpret. On respondent replied, regarding content analysis "…very representative survey". However, one respondent felt that there were questions which were repeated throughout the instrument and wrote "several questions seem to be repeated towards the end, i.e. 17-20" and another respondent critiqued the clarity of question 13D as needing improvement and wrote "13 option d - could have read skill demonstration with narration of skill steps (i.e. omit word repeat)". There was unanimous feedback from 57 respondents, about the ability to provide written feedback in open text questions. One respondent wrote, "Yes, sufficient room was provided for answers."

9.6.4 Correlation analysis

Inspection of a correlation matrix depicts the presence or absence of interrelationships among a set of variables, or the set of items in a scale. It is a summary of the associations between items in a scale (Pett et al., 2003). Scrutiny of the matrix in Figure 9.1, revealed the presence of many coefficients with a numerical index ranging from negative to positive values, which indicate the strength and direction of the relationship between two items (Johnson & Christensen, 2012). As a guideline, the strength of the relationship between variables can be broadly classified into small (r=0.1-0.29), medium (0.3-0.49) and strong (0.50-1.0) (Cohen, 1988). Review of the matrix identified coefficients with a numerical index of 0.3 or greater, as well as a clustering of items. For example in Figure 9.1, the items assigned a darker blue hue in the bottom lower right hand corner of the matrix identify there is a cluster of items with a small to medium strength of correlation, this suggests an underlying latent factor within the item correlation matrix (De Vellis, 2012). Visually, we could identify that there were four clusters of items demonstrating this relationship between the items in the correlation matrix (Pett et al., 2003). Therefore, we could justify progressing to perform EFA. This conclusion can be further tested using Horn's parallel analysis (Horn, 1965), a technique to identify the number of factors which cluster within an item pool and can be extracted (Johnson & Christensen, 2012).

Figure 9.1: Correlation structure of 27 items for factors of skill practice feedback, cognitive overload, teach new skill and assist learner's skill acquisition.

9.6.5 Parallel analysis

Performing parallel analysis commences with generating a Cattel's (1966) scree plot (see Figure 9.2).The plot demonstrates the factors within an item pool and their respective eigenvalues or the quantity of information garnered by each factor (De Vellis, 2012. p 128). It is comprised of three sections: a slope, a transition point, and a tail of tapering, and small eigenvalues. The transition point demarcates the locus in the graphic between those factors with an eigenvalue that are less than or greater than one. The slope denotes the factors within the item set that are above the transition point in the graphic. These harvest the largest quantity of information for the item pool (De Vaus, 2002). The schematic in Figure 9.2 depicts four factors with an eigenvalue greater than one, and this suggests that four factors maximises the total variance explained by the combined factors (De Vaus, 2002). However, determining the number of factors which lay above the transition point can be difficult, is subjective and therefore prone to error (Ruscio & Roche, 2012). For this reason, Horn's parallel analysis (Figure 9 – top red line) was used to determine the number of factors to retain within an item pool and this step preceded performing EFA. The resultant parallel analysis plot was transposed over the Cattell's scree plot (see Figure 9.2), and the factors which lay above the juncture of the two graphics, suggests the number of factors to be extracted from the item pool (Horn, 1965; Cattell, 1966; De Vellis, 2012). For the P3 item pool, there are four factors above the point of intersection, suggesting that this number be retained when performing EFA.
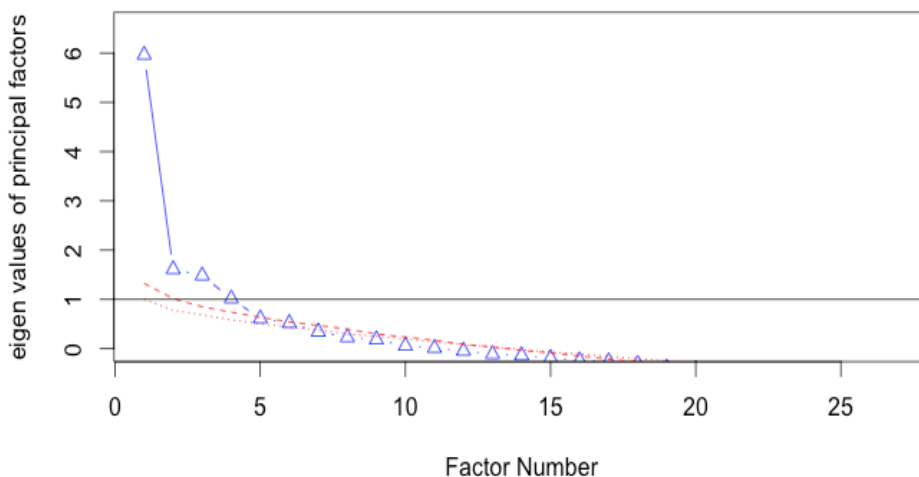
Figure 9.2: Parallel analysis and scree plots confirmed a four factors model existed in the P3 questionnaire.
─△─ Factor Analysis Actual Data
- - - - Factor Analysis Resampled Data

9.6.6   Changes to the item pool

Prior to further data analysis, the P3 instrument number was reduced to 25 items. This reduction occurred because one redundant question was removed from the item pool and two additional items exhibited a negative correlation value; one from the "cognitive overload" factor and one from "skill execution feedback" factor. Retention of these two items in the alpha calculation would negatively influence and skew the data calculations. Importantly, while both items were deleted for statistical merit, they continue to be retained in the instrument variables for noteworthy theoretical tenets. This is because both items are essential to the instructional approach required by an educator to teach a complex psychomotor skill, such as medical ultrasound. Contemporary skill-teaching literature promotes task analysis and deconstruction (Phipps et al., 2008; Jabbour et al., 2011; Leppink & van den Heuvel, 2015) to reduce the potential effect of cognitive overload experienced by the student when first learning a new, complex, and multi-part skill (Nicholls, Sweet, Muller, & Hyett, 2016a). Consequently, permanent removal would leave just two items loading to factor two, cognitive overload. According to Goldman (2009), this would see factor of cognitive overload underrepresented because a minimum of four items per factor is desirable to ensure appropriate representation of the scale or domain. Furthermore, this action may have contributed to a decreased variance for this factor within the scale.

9.6.7   Exploratory factor analysis

Inspection of the item correlation matrix revealed many coefficients with a value of 0.3 or greater, a prerequisite to progressing to factor analysis and extraction. Therefore, we asserted that the items within the SonoSTePs P3 rating scale were both associated with teaching a complex psychomotor skill. To test this hypothesis, we analysed the data using principal component analysis with maximum likelihood (ML) extraction methods, and oblique (direct oblim) rotations. The Kaiser-Meyer-Olkin value was 0.74, which exceeded the recommended value of 0.6 (Kaiser, 1974), and Bartlett's Test of Sphericity p=<0.05 (Bartlett, 1954) reached statistical significance. Principal component analysis revealed four factors, explaining 24.1 %, 9.3%, 8.3% and 6.9 % of the variance respectively. Therefore, using the four-factor model, the total variance across the items was 48 .6%.

Initial factor extraction identified that: 1) the majority of the factors loaded onto the first factor; 2) there were a number of factors which loaded onto two or more factors; 3) most of the factor loadings ranged between 0.22 and 0.8, and while most were positively weighted, there were scattered negatively weighted factors. To further interpret the factors to be extracted from the

item pool, the analysis was re-run with a fixed four factor extraction (derived from the parallel analysis results), and a 0.30 degree factor rotation. The component correlation matrix for the rotated four factors revealed small correlation between the factors, and this suggests that the four factors are independent factors and uncorrelated.

Exploratory factor analysis identified items which clustered around the four main skill-teaching approaches identified by the literature review. The items which explained an instructional approach were observed to be aggregated together. For each factor, the items were recoded to represent the scale or domain. For example, factor one contained items related to feedback and therefore was labelled skill execution feedback (SEF). The items within the factor were also labelled to represent the factor and item number (SEF 1). Factor two contained items related to cognitive overload and was labelled cognitive overload (CO). The items in factor three related to teaching a new psychomotor skill and therefore was labelled teach new skill (TNS). Factor four items were central to assisting the learner's skill acquisition and therefore was labelled assist learner's scanning (ALS). The factors and their respectively recoded items or questions can be seen in Table 9.1.

Table 9.1: The results of initial exploratory analysis showing a four-factor model

Factor	Factor items	Factor loadings	Variance explained	Cronbach's alpha	Alpha for all items (n=25)
Factor 1: Skill execution feedback (SEF) - 7 items	SEF1 SEF2 SEF3 SEF4 SEF5 SEF6 SEF7	0.75 0.75 0.82 0.71 0.75 0.59 0.77	24.1%	0.89	0.83
Factor 2: Cognitive overload (CO) - 2 items	CO1 CO2	0.85 0.69	9.3%	0.68	
Factor 3: Teach new skill (TNS) -7 items	TNS1 TNS2 TNS3 TNS4 TNS5 TNS6 TNS7	0.32 0.66 0.65 0.81 0.67 0.45 0.22	8.3%	0.70	
Factor 4: Assist learners scanning (ALS) - 9 items	ALS1 ALS2 ALS3 ALS4 ALS5 ALS6 ALS7 ALS8 ALS9	0.34 0.50 0.50 0.31 0.42 0.35 0.70 0.32 0.52	6.9%	0.67	

Note: The Cronbach's alpha for factor one SEF was improved by the removal of item 13H. Theoretically, this item was more aligned with the items in factor three TNS and therefore was placed in this item pool. Also, item 13B is related to the theoretical principles of teaching a new skill and was therefore moved from factor two cognitive overload and placed in factor three TNS. Additionally, this change improved factor two cognitive overload Cronbach's alpha from 0.51 to 0.68.

The process identified groupings of items and four factors. The item groups were recoded according to the predominant instructional step they mostly closely represented when teaching a psychomotor skill.

9.6.8   Reliability - internal consistency

Table 6 provides a comparison of the reliability information for each of the four factors and the total items. The initial reliability of the four-factor scale ranged from 0.67 to 0.89 for each of the factors. The reliability assessment for the combined rating scale items (n=25) was 0.83. For two of the factors (ALS and CO) this did not meet the generally accepted 0.7 minimum threshold for scale reliability (Johnson & Christensen, 2012; De Vellis, 2012). However, Moore and Benbasat (1991) suggest that the internal consistency, or the extent to which items within each scale are correlated with one another, should be of a value of 0.6 or greater at the initial validation stages. Furthermore, the mean inter-correlations for these factors "ALS" and "CO" were 0.20 and 0.27 respectively, suggesting a moderately good relationship between the items. This further supports

the initial alpha results for these factors was acceptable. Also, both factors contained less than 10 items per construct, and mathematically this makes achieving a Cronbach's alpha of 0.7 or greater difficult (De Vellis, 2012). Acknowledging these limitations and development guidelines, the internal consistency and initial reliability of the four-factor instrument is acceptable.

9.7 **Discussion**

This paper describes the continued development of a new self-reporting instrument which explores sonographer psychomotor skill-teaching perceptions in clinical practice, labelled SonoSTePs.

The main aim of this paper was to chronicle the steps to develop and validate the tool, and to report on the findings of this process. The construct to "teach a psychomotor skill" was theorized from the literature review to be multi-dimensional, so EFA was used to aggregate items or summarise the underlying patterns of correlations between variables into groups which represented the same construct. The decision to adopt a four-factor model was premised on an iterative process which involved subjective assessment and statistically derived data. It confirmed the hypothesis that the items within the SonoSTePs P3 instrument do indeed explore the instructional practices used by health professional to teach a complex psychomotor or procedural skill. Cronbach's alpha for the four factors ranged between 0.67 and 0.89 and these values are acceptable for initial validation of an instrument. However, using the four factor model, the total variance across the items was 48 .6% and this metric suggests that the items within each factor may not be sufficiently diverse to glean reliable professional practice behaviours (De Vellis, 2012). Additionally, the low response rate (*n*=142) and cohort characteristics may have also influenced and attributed to the P3, overall data outcome.

The response rate to the SonoSTePs P3 instrument is representative of current online response rates to Survey Monkey which range from 8- 36 % (Raffi et al., 2012). However, the factors influencing this result may be related to the survey being dispersed over a 14-week period which included the school holidays, and the Christmas and New Year break. This is because the breakdown of the cohort demographics indicated that the majority of the professional cohort were females employed in a part-time capacity. The profile of the cohort which participated in the P3 validation is indicative of the broader professional demographics of the Australian sonography profession (Australian Sonographer Accreditation Registry (ASAR), 2011). Therefore, because the survey was dispersed over the main summer and Christmas holiday break, the large majority of

the cohort may not have had time to complete the survey. Arguably, this has contributed to the lowered response rate and therefore increases the non-response bias, which then affects reporting reliability. We suggest that a salient outcome of this project is to recommend that surveys striving to maximise their response rates do not include the Christmas, New Year holidays, and other national vacation periods.

The response rate to the P3 validation survey also poses an analytical conundrum. The sample size used to explore factor analysis may not be sufficient (n=123), because usually a minimum of 150 respondents is required to mitigate against item assignment errors and response bias (Pett et al., 2003; De Vellis, 2012). Nunnally (1978) reports that ten respondents are required for every item being analysed, to ensure a stable factor pattern is calculated. However, Tabachnick and Fidell (2007) and Stevens (2002) assert that a ratio of five or more participants per rating scale item is sufficient to perform EFA. The current item to respondent ratio is approximately 1 to 4.8 and based on this criterion, may be insufficient for initial validation. Therefore, a larger cohort study would be required to gain reassurance of the item communalities and a stable factor pattern (De Vellis, 2012).

The representativeness of the cohort undertaking the validation of the P3 instrument may not, as we purported, have the pedagogical knowledge related to teaching a complex psychomotor skill. Therefore, the current factor pattern, and communalities may not be representative of a larger sample number. For example, a large majority (78%) of the cohort reported that they had no credentialing in clinical health education. The remaining respondents (22%) identified that they had either: completed a graduate diploma in health education or completed a course such as "train the trainer" or Certificate IV in Workplace Training and Assessment. Therefore, the validation cohort may not be cognisant of the pedagogical processes required to teach complex psychomotor skills, such as those used in medical ultrasound. These cohort attributes may have unexpectedly introduced reporting bias and error which we suggest has been further magnified by a 17% response rate.

9.8   Limitations

As with all research there are potential limitations. The primary shortfall of this study relates to the small sample number and consequently the sample-to-variable ratio. A reduced respondent-to-item ratio may cause interpretation effects in sampling error, and low correlating items being misplaced within the factors (Pett et al., 2003).

9.9　Conclusion

The newly developed SonoSTePs P3 instrument after initial validation is comprised of a seven-point Likert-type rating scale, with good discriminant validity that contains 25 items. Initial EFA has identified four factors linked to teaching a psychomotor skill and these are corroborated by contemporary skill-teaching literature. The instrument internal consistency for the total pool of items is good. The SonoSTePs instrument may, after undertaking additional exploratory and confirmatory factor analysis on a larger cohort, establish a reliable and valid instrument that can be used to tease out the skill-teaching behaviours of sonographers and other users of diagnostic medical ultrasound.

9.10　Conflict of Interest

9.11　Acknowledgements

9.12　The Ongoing Development of the SonoSTePs Tool Following the P3 Survey

The P3 instrument initially comprised of 27 questions. Three of the questions contained a combined pool of 25 rating scale items. Following the P3 survey and prior to dispersing the national SonoSTePs survey, further changes were made to: (1) the rating scale items, and (2) one stand-alone question in the survey. In the P3 instrument, question 21 asked, "When teaching clinical scanning skills do you provide feedback during the scanning examination?" The participant could select from three responses: yes, no, or sometimes. However, this question had been asked in the rating scale items and was therefore redundant. Repetition of instrument items should be avoided to reduce the length of the survey and help minimise survey fatigue (Creswell, 2008; Schleyer & Forrest, 2012).

Following consultation with a statistician who had expertise in survey design, the 25 rating scale items were further refined before the instrument was used again. In total, there were 14 rating scale questions which were either modified, rewritten, or added to the national survey

instrument. Additionally, one item (14D) was removed from the item pool and the merit of this decision is reviewed at the end of this section. After these changes, the national SonoSTePs instrument contained 34 rating scale items distributed across three main sections which explored the domains or scales related to teaching a clinical skill (see Appendix 3). The justification for these changes was that some of the questions lacked specificity and clarity; therefore, they may not adequately explore the specific scale that they related to. To have kept these questions in the instrument in their current format may have hindered the quality and reliability of the captured data (Creswell, 2008; DeVellis, 2017). There was debate within the research team about the intention to further modify the rating scale items. This is because the provisional psychometric analysis of the P3 data suggested that the instrument collected reliable and valid data (Nicholls, Sweet, Muller, Hyett, & Ullah, 2017). However, following a focused review and analysis of the rating scale items we identified that further changes were warranted. For example, in P3, item 13H, the respondent was asked, "When teaching a new scanning skill to a sonographer do you provide feedback on the learner's skill performance?" The wording of the question was imprecise and did not isolate the point in time that the feedback was provided. For example, feedback can be provided during the skill, which is referred to as in-task feedback; alternatively, it can be provided at the completion of the practice performance, referred to as terminal or end-task feedback (Walsh et al., 2009). Additionally, feedback can be provided in different formats: for example, verbal information or physical guidance (Dresang et al., 2004; Kantak & Winstein, 2012; Ong, Dodds, & Nestel, 2016). Consequently, the question was split into two items in the P4 instrument. Questions 16A and 16B explored whether the educator provided feedback during and at the conclusion of the skill practice performance. Question 16C was added to the P4 rating scale to identify whether the educator gave limited feedback in the presence of the patient. Similarly, question 16D explored whether the educator delivered feedback using a model to guide delivery and content at the conclusion of a practise performance. One feedback model that can be used to structure and deliver two-way feedback to the learner is proposed by Pendleton et al. (1984). It was an oversight not to have asked participants whether they used a feedback model to frame the two-way conversation about the practise performance with the learner. Nonetheless, this broad question provided the context for proceeding with more focussed questions on the sonographer educator's specific behaviours and knowledge when providing feedback to the learner. Question 13A was included to explore whether participants used a published skill-teaching model to teach psychomotor scanning skills. Several items subsequently explored the skill-teaching practice behaviours of the respondents.

Many of the P3 instrument rating scale questions were shortened before they were used in the national SonoSTePs survey. These changes were made to the items to reduce the question length, improve clarity, and help minimise survey fatigue (Creswell, 2008; Schleyer & Forrest, 2012). The revised rating scale items that are related to specific aspects of teaching a psychomotor skill are identified in Table 9.2. Four of the items (13G, 13H, 16A, and 16B) can be seen loading, or relating, to two scales.

Table 9.2: Teaching scanning skills in clinical practice: scales and correlating national survey items

Dimension	Domain/Scale	Scale description and respective rating scale question
Teaching a clinical skill	Teach new skill	The extent to which skill tutors execute skill-teaching elements described by motor-learning authors to teach psychomotor skills (13A, 13C,13D,13E,13F) <u>SUB-SCALE</u> **Recognition of prior learning** The extent to which tutor establishes learners prior cognitive and psychomotor knowledge on skill topic (13 B, 14A) <u>SUB-SCALE</u> **Simulation** The extent to which tutor uses simulated patient or phantoms to teach part or whole task clinical scanning skills (14J, 14K)
	Cognitive Overload	The extent to which tutors limit the quantity of information taught in a teaching session (14B, **16B**, 16C) The extent to which tutor performs task analysis (deconstruction) prior to teaching the skill (14C,14D,14E) The extent to which the tutor provides concurrent feedback during skill practice (13I, **13G**, **13H**, 14 F,**16A**,16C)
	Visual Exemplar	The extent to which a tutor performs a silent skill demonstration to provide a visual standard of performance of skill execution. (13C,13L, 14G,14I)
	Immediate skill error correction	The extent to which tutor corrects incorrectly performed skills as they occur (**13G**,**13H**,14F, **16A**)
	Skill practise and feedback	The extent to which the tutor provides deliberate and supported practise opportunities in short skill sessions (<60 minutes), rather than one long session, to practice skills with feedback on performance. Skill practise (13J, 13K,14H) Feedback (**16B**,16D, 16 E, 16F, 16G, 16H,16I, 16J, 16K)

These many changes to the P3 SonoSTePs instrument culminated in the national survey containing 25 questions. There were three questions which contained a total of 34 rating scale items.

9.13   Summary

This chapter has presented the ongoing development of the SonoSTePs instrument and the steps required to establish the statistical or psychometric properties of the instrument. The development of a reliable instrument is an iterative and ongoing process. Therefore, following the analysis of the P3 instrument, and prior to progressing to use the SonoSTePs to survey the cohort of Australian sonographers, the rating scale items in the instrument were further refined, and one question was removed from the instrument. These changes resulted in questions which were more concise and relevant to the scales or domains related to teaching a psychomotor skill. However, these necessary changes precluded the further advancement of the instrument's statistical and psychometric properties: for example, performing confirmatory factor analysis.

10 NATIONAL SURVEY OF AUSTRALIAN SONOGRAPHER PSYCHOMOTOR SKILL-TEACHING PRACTICES: AN INAUGURAL REPORT

The SonoSTePs instrument had progressed through several iterations of development over an eighteen-month period and these developmental and statistical outcomes have been described in Chapters 8 and 9. The next step of the project involved undertaking a survey of Australian sonographers using the developed SonoSTePs instrument and reporting the research findings. This chapter chronicles the steps that were used to perform this final stage of the research in the later stages of 2014. The format of this chapter mirrors the template used to report the development of the instrument and then the initial validation of the SonoSTePs tool in Chapters 8 and 9.

10.1   Introduction

As already established in this thesis, complex psychomotor skills are required to perform an ultrasound examination and there is very little theory or practice evidence about how these skills are taught. There is anecdotal evidence that the sonography profession uses a master-apprentice, or two-step, skill-teaching approach to teach psychomotor scanning skills. The two-step model involves the expert performing a narrated skill demonstration of the skill steps and then the learner practices the skill steps (Archer et al., 2015).There is a lack of research about how the sonography profession, in Australia or globally, teaches the psychomotor scanning skills required for clinical practice. Without this baseline knowledge about the current teaching approaches that are being used there can be no critical review of the pedagogical approaches used to teach scanning skills. To address this deficit in knowledge, a survey tool was purposefully developed, to collect data about sonographer skill-teaching practices, labelled SonoSTePs (Nicholls et al., 2016b; Nicholls et al., 2017). The aims of this research were to: (1) determine whether the two-step model was being used by sonographers to teach scanning skills, (2) identify what pedagogical approaches described in the motor-learning literature, are being used by sonographers to teach scanning skills, and (3) explore whether heuristic instructional approaches were being used to teach psychomotor scanning skills.

10.2 Method

10.2.1 Study design and population

A national cross-sectional survey was undertaken of all qualified sonographers registered in Australia with ASAR. An email was sent by ASAR to the sonographers who had 'opted in' to receive professional electronic communication.

10.2.2 Questionnaire design and distribution

The final SonoSTePs instrument comprised of 25 questions. Three of the questions contained 12 or fewer rating scale items which explored the domains or scales related to teaching a complex psychomotor skill. A seven-point Likert-type rating scale was used. The instrument was structured into four sections: (1) demographics and professional practice information which comprised of nine questions, (2) sonographer skill-teaching and feedback practices which comprised three rating scale questions and four text questions, (3) sonographer training and education information which comprised eight text questions, and (4) one text question enquiring about the time taken to complete the survey (see Appendix 3).

The survey was administered electronically using SurveyMonkey software. A pre-test was performed prior to dispersing the SonoSTePs survey to ensure that there were no technical issues with accessing and completing the survey. The pre-test 'dummy' survey responses were removed before commencing the national survey. In September 2014, the ASAR administration staff emailed a letter of introduction and a hyperlink to 3151 sonographers. Sonographers were invited to voluntarily and anonymously participate in the research project. Three reminder emails were sent at four, seven, and 10 weeks after the initial invitation. Responses were collected over an 11-week period from the first week of September to the third week in November 2014.

10.2.3 Sampling approach

A census sampling approach was used to ensure that data was collected from a large and representative proportion of the population. Creswell (2008, p. 156) argues that a sample number of at least 350 participants is required to ensure the collected data is transferable and representative of a population. To achieve this number of responses, all sonographers registered with the ASAR were invited to participate in the research. However, those respondents who performed ultrasound in Queensland were excluded from the national survey analysis. This is because the Queensland cohort had been previously sampled to undertake the third pilot of the SonoSTePs instrument (see Chapter 9). Consequently, to avoid contamination of the final data set,

it is a research standard to exclude the previously sampled population used for the purpose of validating the instrument and performing exploratory factor analysis (Creswell, 2008; Kumar, 2011; Sarantakos, 2013; DeVellis, 2017).

10.3 Ethics

Ethical approval from the Flinders University Social and Behavioural Research Ethics Committee was obtained prior to study commencement (SBREC project number 5584). Participation was voluntary and anonymous.

10.4 Data Entry and Analysis

All collected data were downloaded from a secure SurveyMonkey account at the website http://www.surveymonkey.com/ into a Microsoft Excel spreadsheet, checked for completeness, and then imported into SPSS (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp. Statistical package for Social Sciences, SPSS, version 25) for descriptive and comparative statistical analysis. A 2-sample z-test was used to compare the difference between two proportions within the one cohort http://epitools.ausvet.com.au/content.php?page=z-test-2. Responses to open-ended questions were evaluated using content analysis (Saldana, 2009; Green & Thorogood, 2018). This allowed for the exploration of sonographer perceptions related to teaching scanning skills.

10.5 Results

10.5.1 Response rate

A total of 595 participants commenced the on-line survey; however, three responders did not complete any of the survey questions and those participants were deleted from the data set. Therefore, 592 (19%) participants completed the on-line survey. Sixty-four responses were excluded as these participants failed to complete a third, or more, of the rating scale questions. Therefore, 528 responses were included in the national analysis. Throughout the review of the results the number of participants who responded to each question varied. Consequently, not all respondents answered all questions and the population of responses will vary; thus, the number of response population will be given (e.g. as 'n=respondents/total respondents') for each result provided in the text. The mean time to complete the survey was 14 minutes.

10.5.2 Demographic information and professional practice experience

The demographic and professional practice experience of the respondents is summarised in Table 10.1. The median age of the respondents was 46 years, and the majority were female (78%). The context of the respondents varied. Most respondents (58%) worked in private practice, while 32% practiced in public hospitals, 3% in private hospitals, 4% in private practice and public hospitals, and 3% in other combinations. The participants performed a wide range of ultrasound examinations including general (54%), cardiac (21%), obstetrics and gynaecology (12.5%), or vascular sonography (6%). A small number of respondents exclusively performed paediatric (2%), breast (1.5%), and MSK (1.0%) sonography. Alternatively, they were employed to perform a combination of ultrasound: for example, general and cardiac sonography (1.5%). Three (0.5%) of the respondents were not employed in a clinical capacity.

Regarding their employment, most responders reported that they worked in a full-time capacity (50.5%) or a part-time (45%) capacity. A small number of participants reported that they were on maternity leave 2.5% (n=13/521) and the remaining 2% (n=11/521) of responders indicated that they were employed as either a locum, contractor, or they were retired. The majority of respondents 75% (n=393/524) reported that their primary role was to perform clinical scans. The remainder of the cohort were employed in the capacity as a: 14.5% (n=77/524) chief sonographer, 6% (n=32/524) tutor sonographer, 3% (n=14/524) clinical supervisor, and 1.5% (n=8/524) university lecturer.

Table 10.1: The demographic and professional practice information of the participating sonographers

Variable	Category	Number (*N=*)	Percentage (%)
Age (years)	21-75 years; mean 45.6 years		
Gender	Female	401	78%
	Male	114	22%
Type of practice	Public practice	165	32%
	Private practice	302	58%
	Hospital	17	3%
	Equal public/private	21	4%
	Other combinations	16	3%
Hours of employment	Full-time	263	50.5%
	Part-time	234	45%
	Other combinations	24	4.5%
Type of ultrasound scans performed	General	283	54%
	Cardiac	111	21%
	Obstetrical and gynaecological	65	12.5%
	Vascular	33	6%
	Paediatric	9	2%
	Breast	8	1.5%
	MSK	5	1.0%
	Multiple areas	8	1.5%
	Not employed in a clinical capacity	3	0.5%
Ultrasound Qualification	Graduate Diploma	266	50.5%
	Diploma of Medical Ultrasound-ASUM	167	32%
	Grandfathered	35	6.5%
	TAFE certificate in Ultrasound	5	1%
	Master of Ultrasound	34	6.5%
	Doctorate	6	1%
	America Registry of Diagnostic Medical Sonography	7	1%
	Others	12	1.5%
Location of employment	New South Wales	227	43%
	Victoria	135	26%
	Western Australia	59	11.5%
	South Australia	48	9%
	Tasmania	11	2%
	Australian Capital Territory	11	2%
	Northern Territory	8	1.5%
	Multiple states	5	1.0%
	Queensland	2	0.5%
	New Zealand	15	3%
	International location	3	0.5%

Note: TAFE refers to a College of Technical and Further Education

10.5.2.1 *Geographical location of responders*

Responses were received from sonographers residing in all Australian states and territories. The responses from Queensland were excluded from this analysis as this cohort had been used to perform the P3 survey (see Chapter 9). As shown in Table 10.1, the largest group of responders were from New South Wales (43%, *n*=227/524), followed by Victoria (26%, *n*=135/524), Western Australia (11.5%, *n*=59/524), and South Australia. (9%, *n*=48/524). The number of respondents that were performing ultrasound examinations in each of these four states reflected the distribution of the qualified workforce in 2014 (ASAR 2014a) (see Table 10.2).

Table 10.2: Number of qualified respondents invited from each of the four largest Australian states

Australian State	Percent of national workforce invited to complete the survey (*n-3151, 2014*)	Percent of respondents who participated in the survey
New South Wales	45%	43%
Victoria	28%	26%
Western Australia	11%	11.5%
South Australia	11%	9%

The results show that the percentage of sonographers who completed the survey was similar to the percentage of sonographers who were invited to participate in the research, suggesting that the number of SonoSTePs participants for each of these states reflected the distribution of the qualified workforce in 2014.

10.5.2.2 *Ultrasound qualifications*

The majority of respondents had completed a graduate diploma in medical ultrasound (51%, *n*=266/525) (see Table 10.1) or a diploma of medical ultrasound (32%, *n*=167/525) through the Australasian Society for Ultrasound in Medicine. An equal number of respondents had completed on-the-job credentialing (6.5%, *n*=35/525) or a masters degree (6.5%, *n*=34/525) in ultrasound. A small number of respondents had completed a certificate is ultrasound 1% (*n*=6/525), attained a doctorate in ultrasound (1%, *n*=6/525), completed the American registry of diagnostic medical sonography credentialing (1%, *n*=7/525), or elected not to answer the question (1%, *n*=4/525).

Most respondents (75%, *n*=393/524) reported that their primary role was to scan patients. Other roles included working as a chief sonographer (15%, *n*=77/524), tutor sonographer (6%, *n*=32/524), clinical assessor supervisor (2.5%, *n*=14/524), or university lecturer (1.5%, *n*=8/524).

Most of the respondents (85%, *n*=443) worked with two or more sonographers; however, 11 % (*n*=56/521) worked at a single sonographer practice, and the remaining 4% (*n*=22/521) worked as either a locum or were not employed in a clinical capacity. The majority of the participants 83% (*n*=394/474) reported that they demonstrated to their work colleagues, during the course of their daily scanning, how to image or measure an organ or structure with ultrasound. However, 15% (*n*=72/474) did not provide this support to their peers, and 2% (*n*=8/474) identified themselves as not employed in a clinical practice role.

10.5.2.3 ***Clinical health education qualifications and training***

There were two questions seeking information about the respondent's educational preparation for their teaching and supervision role; one about informal learning and short courses and one about completing formal tertiary qualifications.

The first question explored whether sonographers had undertaken further informal (non-university) training. There were 476 responses to this question. Most respondents (*n*=360/476, 76%) reported that they had not undertaken *specific training* (for example, 'train the trainer course') in clinical health education. Almost one quarter of respondents (*n*=116, 24%) had completed additional and informal training. A 2-sample z-test was used to compare the difference in the credentialing between the samples who had (*n*=116) and had not (*n*=360) completed informal clinical health education training. The 2-tailed analysis showed that there was a statistically significant difference z=10.1, p <0.001 in the educational training between the two cohorts.

Content analysis of open-text responses (*n*=97) exploring what type of further training the respondents had undertaken, (*n*=97) found that most participants who had completed specific (non-tertiary level) clinical education training had done one of four continuing development courses: (1) the 'train the trainer' course (*n*=18); (2) a clinical supervision course (*n*=50); (3) the assessors course to examine students completing the Diploma of Medical Ultrasound (*n*=3); or (4) the certificate four in workplace training and assessment (*n*=5). One participant had completed a clinical supervision and 'train the trainer' course. The remainder of the cohort had completed a formal qualification (*n*=14) or provided an ambiguous response (*n*=8), for example, on respondent wrote, 'CSU'.

The respondents who identified that they had completed training in clinical supervision workshops specified that the education had been provided by private teaching companies or alternatively by

Australian professional organisations such as the ASA, or ASUM. The majority of those respondents who had completed non-university training in clinical health education had attended masterclass courses or focus workshops, at annual national conferences, or dedicated weekend/day workshops. The respondents (*n*=76) in a second open text question stated that they attended educational training provided by the ASA or ASUM (66%, *n*=50/76), or alternatively, other conferences such as 'Echo Australia' (*n*=2/76). These statistics do not sum 100% because those participants who reported that they had undertaken a 'train-the-trainer' course were not asked to specify where they had completed the course. Forty eight percent of the respondents who had completed extra training in clinical health education (*n*=115) reported that they used a skill-teaching model to teach scanning skills. Compared to 41% of those respondents (*n*=348) who had not completed extra credentialing. A 2-sample *z*-test was used to compare the difference in the credentialing between the two cohorts who had (*n*=116) and had not (*n*=360) completed extra clinical health education training. The 2-tailed analysis showed that there was a statistically significant difference *z*=10.1, *p*<0.001 in the number of sonographers who had not completed educational training compared to the cohort that had undertaken further clinical health education.

The second education preparation question explored how many of the respondents had completed, college or tertiary credentialing in clinical health education. The results of this study found that nearly two thirds (62%, *n*=288/468) of the respondents identified that they had not completed any formal tertiary or advanced level qualification in clinical health education. Those respondents (38%, *n*=180/468) who had completed additional tertiary clinical health education reported that they completed: a Graduate Diploma in Health Education (23%, *n*=108/468), graduate certificate (5%, *n*=25/468), masters by coursework (4%, *n*=19/468), doctorate (2%, *n*=8/468), masters by research (2%, *n*=9/468); Bachelor of Education (0.2%, *n*=1/468) and the remainder of the cohort selected that they preferred not to answer the question (2%, *n*=10/468). A 2-sample *z*-test was used to compare the difference between each of the cohorts who had (*n*=180) and had not (*n*=288) completed additional tertiary credentialing in clinical health education. The 2-tailed analysis showed that the level of educational credentialing between these two groups was statistically significant, *z*=5.1, *p*<0.0001.

10.6   The Pedagogical Approaches Used to Teach Psychomotor Scanning Skills

10.6.1 The reported pedagogical approaches to teach a psychomotor scanning skill

There are suggested psychomotor skill-teaching models that can be used to guide the teaching and learning of a psychomotor skill. Most responders (58%, n=294/509), identified that they did not use a skill-teaching model to teach psychomotor scanning skills. As shown in Table 10.3, most respondents (86%, n=450/520) reported that they always, nearly always, or frequently taught scanning skills using an approach which involved performing a skill demonstration with a verbal overlay of the skill steps to accompany the skill. Next, the learner practised the psychomotor skill. Therefore, these results suggest that a two-step model is being used to teach psychomotor scanning skills.

The duration of the supervised practice sessions varied. The majority of respondents (64%) used numerous short practice sessions of less than 60 minutes, and 42% used long practice sessions of over 60 minutes. To better understand the impact of the skill-teaching practices used by the two cohorts, a Wilcoxon Signed Rank Test was performed. The results revealed that the number of responders who used short practice sessions to teach scanning skills, compared to those who used long practice sessions, was statistically significant, z= -8.31, p< 0.001. Therefore, the dominant instructional approach used by the responders in this study involved short skill practice sessions of 60 minutes or less and this practice behaviour was statistically significant.

Nearly one half of the responders indicated that they used long skill practice sessions. Content analysis of the open text responses indicated that a dominant factor for the use of longer practice sessions was due to the unpredictable nature of the clinical space and the ad-hoc opportunities to teach and practice scanning skills. Long practice sessions were encouraged by the sonographer educator to compensate the learner for lost skill practice opportunities. Therefore, when a window of time became available long practice sessions, of greater than 60 minutes, it encouraged the educator to compensate the learner for lost practice opportunities. The exception was for those learning paediatric ultrasound. This later finding is not unexpected, as most paediatric scans need to be completed quickly and efficiently in order to minimise the distress caused to the child. Protracted and ongoing scanning of children is a tacit and unacceptable norm of the sonography profession.

Other pedagogical approaches are also required to support a learner's psychomotor skill acquisition. Table 10.3 shows these behaviours and the reported practice behaviours by the

respondents. For each question, the sample size varies as identified. The result show that the majority of the respondents (85.5%, n=448/522) established the learner's prior skill knowledge before they taught the skill. While many respondents identified that when they taught psychomotor scanning skills they provided: (1) guidance and coaching when teaching scanning skills (92%, n=478/519), (2) immediate error correction when a skill was performed incorrectly (79%, n=413/520), (3) in-task feedback during the skill performance (51%, n=244/482), and (4) physical guidance to support a learner's skill acquisition (65%, n=313/486).

Many suggested pedagogical approaches, to teach a psychomotor skill, were not used by the respondents. For example, less than half of the participants reported that they performed a silent skill demonstration (46%, n=239/517). Most of the participants (44%, n=226/517) reported that they did not ask the learner to describe each skill step before they, the sonographer educator, demonstrated the corresponding skill step. Less than half of the respondents (48%, n=251/521) reported that they asked the learner to describe each skill step before the learner performed the respective skill step. Moreover, (90%, n=472/520) of respondents said they do not provide a silent video/exemplar of the skill as a resource to facilitate the observational learning of the psychomotor skill. In Appendices 6, 7, and 8, the participants' responses to the seven-point Likert-type rating scale categories for the 34 rating scale questions can be reviewed.

Table 10.3: A summary of the main reported skill-teaching practices by participating Australian sonographers

Teaching Practice	% do	% Sometimes	% do not	Response count
Use a skill-teaching model	23 %	19%	**58%**	509
Prior knowledge	**86%**	9%	5%	522
Silent demonstration	38%	16%	**46%**	517
Repeat demonstrate-verbalize steps	**86%**	8%	6%	520
Repeat: Learner verbalizes steps-educator demonstrates	35%	21%	**44%**	517
Learner verbalises steps and performs	**48%**	20%	32%	522
Immediate error correction	**79%**	15	5%	520
Guidance & coaching	**92%**	7%	1%	519
Physical guidance	**65%**	20%	15%	485
Short skill practice	**64%**	21%	15%	514
Long skill practice	40%	17%	**43%**	517

About rating scale questions and responses: When teaching a sonographer an ultrasound scanning skill, do you? The seven-point rating scale frequency distribution have been condensed to three options. The category "do" corresponds to the categories of often, nearly always, and always. While, the category "do not" corresponds to the categories of never, rarely, and infrequently. For individual frequency responses to each rating scale and respective confidence intervals please refer to the table in Appendix 6. Values in **bold** indicate the most common responses.

10.7 In-task and End-task Feedback

The results of this study found that most respondents provided physical guidance and guidance and coaching, or in-task feedback, when they taught psychomotor scanning skills. The majority of respondents reported that they did (92%, *n*=478/519), did not (1.0%, *n*=6/519), or sometimes (8%, *n*=35/519) provided guidance and coaching when teaching scanning skills. As can be seen in Table 10.4, (65%, *n*=313/485) of participant's reported that they assisted a learner's scanning by holding and guiding their scanning hand, referred to as physical guidance. Also, approximately half of the cohort (51%, *n*=247/482) provided in-task, or concurrent, feedback to the learner as the skill was being practiced. While 66% of the respondents (*n*=311/481) reported that they limited their verbal feedback to the learner when teaching scanning skills on the job and in front of the patient.

Table 10.4: Reports the percentage of practice behaviours used by sonographers when they provide in-task feedback to learners while performing a scanning skill

Teaching Practice	% do	Sometimes	% do not	Number
Guidance & coaching	**92%**	7%	1%	519
Physical guidance	**65%**	20%	15%	485
Provide feedback during skill performance	**51%**	29%	20%	482
Limit feedback in the presence of the patient	**65%**	26%	9%	481

The seven-point rating scale frequency distribution have been condensed to three options. The category "do" corresponds to the categories of often, nearly always, and always. While, the category "do not" corresponds to the categories of never, rarely, and infrequently. For individual frequency responses to each rating scale and respective confidence intervals please refer to Appendix 8. Values in **bold** indicate the most common responses.

10.7.1 Feedback practices of the responders.

Most respondents (94%, *n*=461/525) reported that they provided verbal feedback to their colleagues (see Table 10.5). The remainder of the cohort identified that they either did not know how to provide feedback (1.5%, *n*=7), that they did not work with another sonographer (2.5%, *n*=12), or they preferred not to get involved with the provision of feedback to their peers (2%, *n*=9). The majority of the respondents, (70%, *n*=336/479) reported that they did not use a feedback model to deliver end-task verbal feedback.

Regarding the time-point that feedback was provided to the learner, the majority of responders (83%, *n*=403/484) reported that they provided feedback at the end of a skill performance. A similar percentage of responders (84%, *n*=402/483) reported that they stated to the learner what was done well and why. The majority of responders (81%, *n*=388/481) reported that they pointed out how the skill performance could have been improved. Whereas, 60% (*n*=287/481) of respondents asked the learner to identify what aspects of their skill practice could be improved and how. Approximately two thirds of the respondents (68%, *n*=322/497) provided a summary of the skill performance to the learner and identified practice areas for future improvement. Finally, nearly all participants (93%, *n*=445/481) reported that they ended the feedback session by providing positive comments to the learner.

As seen in Table 10.5, less than half the cohort of responders (47%, *n*=229/483) identified that they asked the learner to provide an overview of how they felt their practice performance went and an almost equal number of responders (47%, *n*=226/483) asked the learner to identify what they did well and why. Whereas, 60% (*n*=287/481) of respondents asked the learner to identify what aspects of their skill practice could be improved and how they would improve the practice

performance. Approximately two thirds (68%, *n*=322/479) of the respondents provided a summary of the skill performance to the learner and identified practice areas for future improvement. Finally, most participants (93%, *n*=445/481) reported that they ended the feedback session by providing affirmative and positive comments to the learner.

Table 10.5: Reports the percentage of practice behaviours used by sonographers when they provide feedback to learners

ANSWER OPTIONS	Do %	Sometimes %	Do Not %	Response count
Provide feedback at the conclusion of a skill performance?	**83%**	12%	5%	**484**
Deliver feedback using a model to guide delivery and content?	13%	17%	**70%**	479
Ask for an overview of skill performance or how they felt they went?	**47%**	27%	26%	483
Learner identifies what was done well and why?	**47%**	27%	26%	483
Educator states what was done well and why?	**83%**	12%	5%	483
Ask the learner to identify what could be improved and how?	**60%**	21%	19%	481
Educator identifies what aspects of the skill performance could be improved and how?	**81%**	14%	5%	481
Educator provides a summary of skill performance and identifies areas for learner to focus on?	**68%**	17%	15%	479
End feedback session with positive comment(s)?	**93%**	6%	1%	481

The seven-point rating scale frequency distribution have been condensed to three options. The category "do" corresponds to the categories of often, nearly always, and always. While, the category "do not" corresponds to the categories of never, rarely, and infrequently. For individual frequency responses to each rating scale and respective confidence intervals please refer to Appendix 8. Values in **bold** indicate the most common responses.

10.7.2 Limiting cognitive load

Approximately two thirds of the respondents reported that they used instructional approaches that are intended to limit the effects of cognitive load when teaching and learning complex psychomotor skills (see Table 10.6). However, the responses to two of the four of the rating scale items which explored whether the participant taught the whole skill in one teaching session (14B), performed task analysis (14C), taught a skill sub-part (14D), and then progressed to linking the skill sub-parts together until whole task practise was achieved (14E) provided inconclusive data about these practice behaviours using the three collapsed categories, "do", "sometimes", and "do not". Therefore, for each of these four rating scale questions, the responses were further deconstructed

and reported for each of the seven-point Likert-type rating scale categories to better understand the pattern of reported teaching practices and behaviours by the participants.

The lack of clarity arose when the responders practice behaviours to question 14B showed that there was little clarity about whether the responders did, did not, or sometimes taught the whole skill in one teaching session. Nearly half of the respondents 45% reported that they did not (never, rarely, or infrequently) teach the whole scanning skill in one teaching session. The number of participants who reported, in their responses to the seven-point rating scale categories, that they taught the whole scanning skill in the one teaching session included: 10.5% (n=52/488) never used this approach, 13.5% (n=67/488) rarely, 21% (n=101/488) infrequently, 30% (n=146/488) sometimes, 14% (n=70/488) often, 7% (n=35/488) nearly always, and 3% (n=17/488) always used this teaching method (see Appendix 7). The largest responses to this question, using the seven-point Likert-type rating scale categories, were to "infrequently" and "sometimes". However, the most responders to any one category identified that they "sometimes" taught the whole scanning skill in one teaching session.

An additional and standalone question, number 21, asked, "When teaching a scanning skill do you teach the entire skill from beginning to end, in one clinical teaching session? The respondents' answers showed that 50% (n=239/471) of the participants reported that they sometimes taught the whole scanning skill in the one teaching session, 27% (n=125/471) did not, and 23% (n=107/471) did use this approach. The rationale and merit for the inclusion of this additional question, number 21, will be presented in the Chapter 11.

To further understand the differing reported behaviours of the respondents to an important pedagogical approach when teaching a complex psychomotor skill, content analysis of the open text responses (n=216) to the second part of question 21 was performed. The individual analysis of the responses identified that 27% (n=58/216) of the responders did not teach the entire scanning skill in one teaching session. A further ten participants responses (~5%, n=10/216) lacked clarity or relevance and could not be grouped into a pattern of behaviour. However, 68% of the participants (n=148/216) identified that their decision to teach the whole scanning skill in one session was dependent upon four factors and they included the: time available to teach the scan; patient well-being, skill level and experience of the learner; type of scanning skill being taught; and business of the department. For example, one respondent stated, "Depends on the patient, the skill, the skill of the student and the time available". While, many of the responders stated,

> … depends on the level of skill of the person learning, if a competent sonographer is learning new areas such as MSK/vascular [ultrasound] the whole scan can be demonstrated, if a newbie [beginner/student sonographer], then I break it down into small bites.

This quote reveals a common viewpoint by many of the participants who responded to this question. It suggests that the respondents make a judgement about two factors when they teach scanning skills. First, they establish whether the learner is a student or a qualified sonographer. Next, they assume that based on the learner's credentialing that they can use differing pedagogical approaches to teach the scanning skill because qualified sonographers already possess the psychomotor scanning skills to be able to scan. Therefore, these responses suggest that many of the participants made a subjective assessment about the learner's scanning ability which is based upon the practice experience and credentialing of the learner.

As can be seen in Table 10.6, 66% of respondents (often, nearly always, or always) performed task analysis and broke a skill down before they taught it (question 14C). However, the seven-point rating scale responses, for this behaviour, included: 3% (n=15/485) never used this instructional approach, 4.5% (n=23/485) rarely, 4.5% (n=23/485) infrequently, 21% (n=103/485) sometimes, 29% (n=141/485) often, 27% (n=130/485) nearly always, and 10% (n=50/485) always used this teaching approach (see Appendix 7). The majority of the responses were clustered around the behaviours related to sometimes, often, and nearly always. Therefore, the aggregation of behaviours to these categories suggests that respondents do perform task analysis. Furthermore, it is possible to perform task analysis and still teach the entire scanning skill on one teaching session; therefore, these two practice behaviours are not mutually exclusive.

Table 10.6: Reports the percentage of practice behaviours used by sonographers when they first teach multi-part and complex psychomotor or scanning skills to learners

Teaching Practice	% Do	Sometimes	% do Not	Number
Teach whole skill in one session	25%	30%	**45%**	488
Break a task down before teaching it	**66%**	21%	13%	485
Teach a sub-part of the task	**61%**	26%	13%	484
Progressively practices sub-tasks until whole-task practice is achieved	**65%**	21%	14%	480

The seven-point rating scale frequency distribution has been condensed to three options. The category "do" corresponds to the categories of often, nearly always, and always. While, the category "do not" corresponds to the categories of never, rarely, and infrequently. For individual frequency responses to each rating scale and respective confidence intervals please refer to Appendix 7. Values in **bold** indicate the most common responses.

More than half of the respondents, 61% of respondents (often, nearly always, or always), reported that they taught each sub-part before teaching another skill sub-part (question 14 D). A review of

the responses to each of the seven-point rating categories showed that participants used this approach with a frequency for each category which included: 2.5% (*n*=13/484) never used this teaching approach, 4.5% (*n*=22/484) rarely, 6% (*n*=30/484) infrequently, 26% (*n*=125/484) sometimes, 28% (*n*=133/484) often, 24% (*n*=116/484) nearly always, and 9% (*n*=45/484) always used this instructional approach (see Appendix 7). The majority of the responses (approximately 25% for each category) were clustered around the behaviours related to sometimes, often, and nearly always. Therefore, the aggregation of behaviours to these categories suggests that respondents do teach each sub-part before another skill sub-part is taught. Thus, for multipart skills which involve the learner understanding how to move the transducer, perform image instrumentation, and image optimisation it is unclear whether this pedagogical approach can be used when the entire scanning skill is taught in the one session. It is suggested that these two teaching behaviours might be mutually exclusive. In other words, it is unlikely that both teaching approaches can be used concurrently when teaching and learning multipart scanning skills.

Approximately two thirds, 65% of the participants identified that they (often, nearly always, or always), continued to progressively practice the skill sub-parts until whole-task practice was achieved (question 14 E). The number of participants who reported, in their responses to the seven-point rating scale categories, that they progressively linked the practise of the skill sub-parts together until whole task practise was achieved included: 3.0% (*n*=15/480) never used this approach, 5.0% (*n*=23/480) rarely, 6% (*n*=30/480) infrequently, 21% (*n*=100/480) sometimes, 29% (*n*=139/480) often, 25% (*n*=122/480) nearly always, and 11% (*n*=51/480) always used this instructional approach (see Appendix 7). The majority of the responses (approximately 25% for each category) were clustered around the behaviours related to sometimes, often, and nearly always. Therefore, the aggregation of behaviours to these categories suggests that respondents do progressively link each sub-part until whole-task practice is achieved. Thus, it is suggested that the progressive practise of skill sub-parts until whole-task practice is achieved may be incompatible with teaching the whole scanning skill in one teaching session.

10.8 Push and Pull Factors Impacting the Pedagogical Approaches Used by Sonographers to Teach Scanning Skills

Respondents were invited through open-text responses to outline and explain their rationale for the instructional practices that they used when they taught scanning skills. Five key themes emerged from the content analysis of the open text responses and these were:

- Limited protected teaching time.

- Perceived skill complexity.

- Learner skill level and credentials.

- Avoiding overwhelming the learner.

- Patient well-being and their willingness to be scanned.

10.8.1 Theme 1: Limited protected teaching time

Many respondents identified that they had little regular teaching time due to working in fully booked and busy departments. Therefore, many practice settings provided unpredictable, ad-hoc and opportunistic teaching opportunities. The limited teaching time served to influence the pedagogical approaches used by the responders.

For example, many respondents pointed out that there was a lack of protected teaching time, and this was problematic for the teaching of scanning skills:

> …the teaching is much more 'ad hoc'" and another highlighted that, "If there is no formal time set aside for training and it is on the job training often you do what you can when you can. This means you may have time to teach a whole technique or it may have to be taught piecemeal as time allows". While another stated that they, "Just grab whatever time we have with the patients that come in.

10.8.2 Theme 2: Perceived skill complexity

Most participants reported that before teaching a scanning skill they subjectively assessed for themselves the degree of difficulty to learn the scanning psychomotor skill. They proceeded to grade the skill into two categories, either simple or complex skill. The outcome of this judgement or classification determined how much of the skill the responder taught the learner in one teaching session. For those skills which were categorised as being complex, the participants identified that they performed task deconstruction and commenced by first teaching the simpler skills and then advanced to those which were more challenging. This practice is referred to as scaffolding (Dent et al., 2017). For example: *"…Complex skills need to be broken down into different parts….Simpler skills can be taught in one session…".* Another respondent pointed out that it *"Depends on skill being learned"*. While another respondent pointed out that it *"Depends on how complex the exam is. Obs* [obstetrics] *is broken into sections, thyroids all in one go"*. Finally, a cardiac sonographer respondent wrote:

> …cardiac sonography is mostly performed as a comprehensive examination; an echo [ultrasound] is complex, multi-layered; training requires breaking down those layers to fundamental 2D

methods, and then adding more information e.g. spectral Doppler and building up the physiologic as well as anatomic layers to the story.

10.8.3 Theme 3: Learner skill level and credentials

Respondents pointed out that the perceived skill level and credentialing of the learner influenced their skill-teaching approach. A judgement was made by the educator about a student's or qualified sonographer's scanning level and capabilities. Qualified sonographers were expected to know how to scan; therefore, the whole scanning skill was usually taught in one session. In contrast, when the learner was a student there was little expectation about their scanning ability. The skill was deconstructed and taught in parts to their level of prior learning and experience. For example: *"If the skill is short and has few elements or is taught to an experienced sonographer then it may be taught in one session"*, while another pointed out that they, "*Base the teaching* [approach] *on their* [the learner's] *ability. If they are less able, they work on one aspect at a time"*. Contrasting teaching approaches are used to teach a student and qualified sonographer. One respondent wrote:

> …depends on the level of skill of the person learning, if a competent sonographer is learning new areas such as MSK/vascular *[ultrasound]* the whole scan can be demonstrated, if a newbie *[beginner/student sonographer]*, then I break it down into small bites.

Another respondent stated, *"…If a qualified always* [teach the whole skill in one session]. *If a student-tailored to their skill level"*.

10.8.4 Theme 4: Avoiding overwhelming the learner

Participants identified that to teach the theoretical content and the scanning skills related to performing an ultrasound examination, in one session, would usually overwhelm the student learner. Indeed, many respondents highlighted that teaching a scanning skill in one session hampered learning and to do so was even pointless. For example, *"Cardiac is too long to teach in one session"* and another wrote that teaching a whole scanning skill in one session *"…would overwhelm them. It is better to break it down, so it is better absorbed".* While another respondent commented that it *"Depends on how much information there is to pass on and also the person and whether they are going to be able to take it all in…"* Finally, two further respondents pointed out that, *"Too much information can confuse the student and therefore not be a useful learning process"* and, *"Too much to learn at one time"*.

10.8.5 Theme 5: Patient well-being and willingness to be scanned

There are many factors which influence the skill practice opportunities available to a learner when they are acquiring scanning skills on the job. Two notable factors include the well-being of the patient and the patient's willingness to be scanned. There is an accepted practice norm that when the patient is sick it is not appropriate for the learner to scan them. One respondent stated that the *"Limitations of the patient'* [When the patient was sick it limited the teaching and practise of scanning skills]*"* impacted upon the skill practice opportunities that were provide to the learner on any one day. The respondents did not isolate the medical conditions that would preclude the learner not scanning the patient. Another respondent wrote that it *"depends on the patient, the skill, the skill of the student and the time available"*. This quote is reflected by many of the respondents who reported that the opportunity for the learner to be scanned was inextricably linked to the patient being willing to consent to the learner scanning them.

10.8.6 Simulation to teach psychomotor scanning skills

Varied forms and frequency of use of simulation where explored. A large majority of respondents (91%, *n*=436/481) reported that they that they never, rarely, or infrequently, use phantoms to assist their teaching of scanning skills (see Appendix 4). Additionally, many respondents (83%, *n*=452/592) reported that they do not use other simulated learning models to teach scanning skills, e.g. plastic manikins, animal models, simulated, or standardised patients.

Forty two percent of the respondents (*n*=204/485) identified that they taught scanning skills on staff members (see Appendix 5). While a further 30% (*n*=145/485) reported that they sometimes used staff members as models to teach scanning skills. The remainder of the respondents (2%, *n*=136/485) reported that they do not use staff members to teach scanning skills.

A small cohort of respondents (between 14-17%) used dedicated simulation instructional aides to teach scanning skills. Content analysis of responses identified that a range of phantoms and "hybrid aides" are used as models to support the teaching and practise of scanning skills. For example, transvaginal and vascular access phantoms, agar jelly blocks, old physics phantom, model of the skull, high fidelity vimidex and transvaginal scanning simulator, blown up glove to represent the uterus, plastic mannequin, and a plastic baby doll.

Respondents reported that they used simulative aids to teach scanning skills to students (*n*=73) and qualified sonographers (*n*=50), in private practice 49% (*n*=48), public hospitals 34% (*n*=33), private training/teaching institutions 11% (*n*=11), and university teaching settings 6% (*n*=6,). More

than half of the cohort 57% (*n*=67/117) did not change their teaching approach when using simulation teaching aides. Approximately one quarter of the cohort identified that they either sometimes changed (*n*=27, 23%) or always changed their teaching approach 20% (*n*=23).

Respondents were asked to explain why they did or did not use simulation to teach scanning skills. Three key themes emerged from the content analysis of the 31 open text responses, and these were: (1) communication is uninhibited and does not require censorship; (2) simulation enables scanning skills to be isolated and purposefully practised; and (3) there is a limited roles for commercial simulators to teach scanning skills.

10.8.6.1 *Theme 1: Communication is uninhibited and does not require censorship*

Teaching psychomotor scanning skills using simulation provided the opportunity for uninhibited and uncensored communication between teacher and learner. The scanning of patients on the job presents unique learning opportunities and some clinical teaching challenges. When scanning skills are taught and practised on the job, the educator fulfils an additional role of a gatekeeper. This is because educators are required to exercise discretion and caution about what and how much information they share about practise performance with the learner in front of the patient. Respondents reported that learning scanning skills in simulation has unique communication benefits, for example: *"There is more emphasis on technique whereas in real-time teaching, respect and communication must be given to the patient as a priority"*. While another respondent pointed out that *"you can talk openly about findings and anatomy which you can't do in front of patients"*. This view is supported by two other respondents who stated that they had the *"time to discuss pathology and findings. Models don't freak out when you discuss pathology"* and *"You can explain in more detail as the simulated patient knows they are there for teaching purposes"*.

10.8.6.2 *Theme 2: Simulation enables scanning skills to be isolated and purposefully practised*

Teaching psychomotor skills in simulation enabled the differing upper limb skill sets, to use the equipment, to be taught separately. It is a challenge for novice operators to be able to perform the skill to move and manipulate the transducer with their transducer operating limb and to also learn how to perform image optimisation and instrumentation with their *other*, console operating limb. The use of simulation is one approach identified by respondents, to teach and integrate the execution of these foundation skills. For example, *"simulation helps beginning students. Feedback is not great for vag* [vaginal] *scans. Good for* [teaching] *tgc* [time gain compensation]*, gain, focus".* One respondent stated, *"Spend more time explaining why the scan needs to be performed a*

certain way and what it is they should be seeing…". Another participant stated that *"cardiac anatomy is complex and the slices we take with the probe is difficult to explain without models and posters. Basic ultrasound also needs reinforcement with visual posters"*.

10.8.6.3 ***Theme 3: There is a limited role for commercial simulators to teach scanning skills***

Several respondents reported that commercial high-end simulators had some teaching limitations. This is because the phantoms lacked the ability to accurately represent the challenges associated with scanning in a real-world context. For example:

> Some of the available simulators….. don't always allow a true representation of the complexity of scanning and finding *[acoustic]* windows, for example, in the real-world environment. Most of the teaching in training is a mix to show students the varying tactics to present good ultrasound images…

While another respondent pointed out that simulation has a role to isolate specific scanning skills and teach these skills, as opposed to using the teaching and learning tool to teach the complete skill. As one respondent stated, "*I have not used the simulator to progress through a complete exam, rather to focus on specific aspects*".

10.8.7 Novel teaching interactions are discovered

Novel teaching interactions between the educator and the student sonographer were identified. Respondents reported through open text responses (*n*=229) that they provided several types and formats of information to learners when they were acquiring and refining clinical practice skills. Respondents described providing information to learners at four time-points across the continuum of the whole clinical practice performance. The type, quantity, and purpose of the information, provided by the educator to the learner differed at each of these four time-points and included: (1) Pre-task clarification, guidance, and practice norms; (2) In-task verbal information and scanning support; (3) Post-task support and information; and (4) End-task or terminal feedback.

Content analysis of the open-text responses revealed unique information was exchanged between the educator and the learner at each of these four time points and these points of exchange are further explored in the following sections.

10.8.7.1 ***Pre-task clarification, guidance, and practice norms***

At the commencement of the clinical practice and prior to identifying the patient for the clinical examination, the respondents described providing the learner with pre-task clarification, guidance, and practice norms to complete the examination. Prior to the learner commencing a

physical scan of the patient, sonographers reported that they clarified the clinical question to be answered during the ultrasound examination and provided additional coaching and guidance to help the learner plan their approach to scanning. For example, *"The student has been grilled to know what to look for but also other pathologies. Selecting the correct transducer. Patient prep"* and *"sometimes at the start. How to provide most appropriate technique to answer the clinical question"*. Additionally, consent was sought by the sonographer to hold the learner's hand and guide it to the correct position on the patient, also referred to as physical guidance, e.g. *"Before scan: if student minds being directed with my hand guiding hers on the probe. Or if she would prefer just verbal instruction…"*.

10.8.7.2 *In-task verbal information and scanning support*

Throughout the execution of the scan as the skill was being practised, the sonographers reported that they provided verbal guidance and physical guidance while the scan was being performed. This is known as in-task information or feedback. Many sonographers reported that one of their roles was to limit and censor the information provided to the learner when the patient was unwell, large, or pathology was encountered. An example is, *"Positioning of the scanner* [transducer] *or student's hand maybe altered during the scan if deemed a simple solution"*, whereas sometimes there were constraints:

> The 'when' aspect of providing feedback all depends on the nature of the subject and case. If the matter is one of a sensitive nature, I would often restrict feedback to the end [of the examination] in a private setting away from the subject e.g. Breast Ca [cancer] or some life altering diagnosis. If the nature of the case is not sensitive and the subject is coherent and consents to being involved in a teaching environment (such pt's [patients] are usually ok with it), then feedback can be provided along the way.

10.8.7.3 *Post task support and information*

During the post-examination write-up period, respondents described providing support and information to the learner to ensure the examination findings were correctly interpreted and written up on the worksheet/report. Respondents reported that this helped with the learner's interpretation of the scan findings and to accurately write up their examination results. For example, one person wrote that they helped with the *"image review and report writing with feedback occur at the end in the write up area"* and another stated they:

> Often compare [the cardiac scan images] and refer to other patients with similar abnormalities and use a bank of images that we have on hand to demonstrate mild, moderate, and severe examples of the lesions…

10.8.8 End-task or terminal feedback

At the completion of the practical performance, after the patient has left the scan room, the educator provided end-task or terminal feedback to the learner. Many respondents stated that the information provided to the learner once the examination had been completed targeted three areas of clinical practice: (1) gathering feedback about how the examination could be improved, (2) exploring how their communication with the patient could have been improved, and (3) linking the feedback to future learning goals. For example, *"…provide feedback on the trainee's interaction with the patient…often ask if* [what] *they think they could do differently, and how would they deal with it next time"*. After the feedback has been provided, one respondent wrote that they *"…discuss learning action plan for continuing educational needs"*.

10.9   Discussion

In this study we surveyed Australian sonographers to try and elicit what pedagogical approaches were used to teach psychomotor scanning skills. This inaugural research is the first survey to explore the skill-teaching perceptions and practice behaviours of sonographers in Australia, or elsewhere in the world.

10.9.1 Typical responder and generalisability of the results

The demographic and work practices of the respondents closely matched the workforce data and is therefore representative of the age, gender, imaging streams, professional practice, place of work, and the educational preparation of the qualified sonographer cohort who responded to this survey. A comparison of this study's demographic and workforce data with state and Census data reported in the sonography workforce report indicate many cohort similarities (Victorian State Government: Department of Health and Human Services, 2016). Furthermore, the upper and lower confidence intervals for nearly all the data supplied in this analysis fall within the 95th centile range. These results, which compare the similarity of the cohort to the broader professional population, suggest that the cohort of sonographers who responded to this survey are representative of the larger population of Australian sonographers.

10.10   The Instructional Approaches to Teach a New Psychomotor Scanning Skill

There are suggested pedagogical approaches that sonographer educators may use to support a learner's initial and then ongoing skill acquisition. As shown in Table 10.7, there are differing

instructional approaches for each of the three stages related to teaching a complex psychomotor skill. Stage one refers to the instructional approaches that are used by the educator before the skill is taught in clinical practice. The instructional steps relevant to stage one includes the educator performing task analysis, establishing the learner's prior knowledge and skill level, and teaching the essential theoretical information linked to performing the skill. Stage two includes the steps used by the educator to physically teach the skill and they involve the steps used to demonstrate and teach the skill, providing immediate error correction, and limiting guidance and coaching. Stage three focuses on the learner intentionally practicing the skill sub-parts until whole-task practice is achieved, followed by the educator providing end-task or terminal feedback.

10.10.1   Stage one of teaching of a psychomotor scanning skill

Stage one of teaching a psychomotor scanning skill includes the instructional steps that the educator performs before the skill is physically taught to the learner. To commence teaching a psychomotor skill, the educator first identifies the psychomotor skill that is to be taught (Phipps et al., 2008). Next, the educator performs task analysis which involves identifying the skill sub-parts that are needed to execute the whole skill (Sullivan et al., 2007; Sullivan, Ortega, Wasserberg, Kaufman, Nyquist, & Clark, 2008; Phipps et al., 2008; Jabbour et al., 2011). The deconstruction of the task into sub-parts conveys to the educator the number of sub-parts there are to perform the skill and also the steps that are needed to teach each skill sub-part (Phipps et al., 2008). Undertaking this teaching step, before the skill is taught, avoids the educator accidently omitting any steps (Sullivan et al., 2008; Phipps et al., 2008) and serves as a guard against the educator incorrectly demonstrating the skill (Clark, Pugh, Yates, Inaba, Green, & Sullivan, 2012).

The skill practice of educators who have progressed to a master or expert level has become automated; therefore, they no longer need to pay attention and think about the skill sub-parts and steps needed to perform the task (Dreyfus, 2016). Consequently, when expert educators teach a psychomotor skill they may inadvertently and unknowingly omit some of the steps needed to perform the task. Sullivan et al. (2008) found that expert gastro-intestinal specialists left out 50% of the steps needed to execute the skill if they did not identify beforehand the steps used to perform a colonoscopy examination, or perform cognitive task analysis. Clark et al. (2012), from a surgical background, also concluded that cognitive task analysis improved the completeness and accuracy of the surgeon's recollection and description of the task steps when they taught a surgical skill. Therefore, the limited literature on this area of skill education suggests that there are tangible teaching and learning benefits from the educator identifying the skill sub-parts and steps

before it is taught. Approximately two thirds (66%) of the respondents reported that they performed cognitive task analysis and deconstructed a scanning skill down into sub-parts before they taught it. A further 29% of respondents reported that they sometimes used this teaching approach and a small number did not use this approach (12%). Therefore, cognitive task analysis is being performed by the majority of the respondents (see Table 10.7).

Most of the participants (86%) reported that they established the learner's prior skill knowledge before they proceeded to teach the skill. Before the sonographer educator teaches a psychomotor scanning skill, they should establish the learner's prior skill knowledge. To do so avoids the educator teaching cognitive and procedural knowledge which is already known. Additionally, clinical teaching time is a limited and valuable resource and it should be used wisely to cover novel content and avoiding disengagement by adult learners, since superfluous and redundant content would be taught otherwise (Rose & Best, 2005; Dent et al., 2017). Therefore, these results suggest that the majority of the responders are maximising the use of their clinical teaching time by establishing the learner's prior knowledge when they teach ultrasound scanning skills (see Table 10.7).

The type and amount of information that is taught to a learner in any one session should be limited (van Merriënboer et al., 2006; van Merrienboer & Sweller, 2010). Nearly two thirds (66%, n=321/485) of the respondents reported that they broke a scanning skill down into discrete sub-parts before they taught it and this reported behaviour aligns with the pedagogical approaches used to reduce a learner's cognitive load. Both van Merrienboer and Sweller (2010) and Young et al. (2014) point out that when complex skills are first being taught and learned the educator should reduce the quantity of the informational being taught, and simplify the teaching of complex theory and concepts that are needed to be comprehended to execute the skill. Consequently, in only one session, educators should not teach novice learners the theory, equipment care, and skill-steps to perform an ultrasound. The volume of information usually results overloading of the learner's finite and limited capacity of their working memory (Leppink & van den Heuvel, 2015). Cognitive load theory shows that there is an impost upon a learner's working memory when a large amount of new information is taught to them at once. Cognitive load management can be achieved by moderating the type, amount, and the complexity of the information taught to the learner during a teaching session (van Merrienboer & Sweller, 2010; Young et al., 2014; Leppink & van den Heuvel, 2015). Consequently, van Merrienboer and Sweller (2010) and Leppink and van den Heuvel (2015) conclude that when complex and multipart

psychomotor scanning skills are being first taught and learned the educator should only teach one skill sub-part which contains no more than seven skill steps.

Approximately two thirds of the respondents (61%) reported that they taught each sub-part before progressing to the next skill part. Approximately two thirds of the respondents (65%, *n*=312/480) identified that they encouraged learners to progressively practiced the skill sub-parts together until whole-task practice was achieved. However, other survey results contradict these reported practice behaviours. As 45% of respondents reported that they did not teach the whole scan at the first teaching session. Consequently, there is a large majority of the respondents (likely 55%) who do teach the whole scanning skill in one teaching session. It is unclear if this occurs all the time or just some of the time. Nevertheless, teaching a whole scan in one teaching session, when the skill is novel and the learner has limited prior learning of the skill, should be avoided. This is because, the quantity and the density of the information that is required to be processed by the learner's working memory, exceeds its capacity (Sweller, 1993; van Merrienboer & Sweller, 2010; Leppink & van den Heuvel, 2015). This places the learner into cognitive overload, and when this occurs, the learner's skill acquisition progress becomes impeded (Leppink & van den Heuvel, 2015).

The respondents provided, in the open text responses, the justification for why they taught a whole skill in one teaching session. The participants explained that they make an evaluation about the scanning ability and the credentials of the learners prior to the teaching session. The open text results suggested that two factors are used to evaluate. First, they establish whether the learner is a student or a qualified sonographer. Next, they assume that, based on the learner's credentialing, they can use differing pedagogical approaches to teach the scanning skill because qualified sonographers already possess the fine and gross motor skills to be able to scan. These learner-based considerations influence whether they teach the skill in sub-parts or the whole scan in one session. Secondly, the complexity of the scan being taught was also a major consideration. Some respondents expressed that it was almost impossible to teach cardiac, obstetric, or breast scanning in one session, because these skills were examples of complex scanning skills. Therefore, it may be that because scanning skills are multi-part and multi-dimensional psychomotor skills, it is simply logical and intuitive for the educators to use task analysis and teaching in sub-parts. Chunking down information enables the learner to grasp the cognitive knowledge or theory related to performing the skill and gain an understanding of the procedural knowledge to perform the task. Other benefits of using these teaching approaches include learners remain motivated as

they succeed at their tasks and goals, and they have an increased level of confidence (Spruit et al., 2014). Consequently, further research is required to identify when and where these approaches are used and whether the self-reported data about these practice behaviours is credible.

Table 10.7, below, presents a comparison of the reported instructional steps by participants who completed the SonoSTePs survey and the suggested instructional steps proposed by seminal authors from the motor-learning domain, to teach a psychomotor scanning skill. The two-step and four-step instructional steps are included in the table to allow comparison of the suggested teaching approaches.

Table 10.7: Comparison of findings with the published skill teaching models.

Stages to teach and learn a psychomotor skill	Instructional steps to teach a psychomotor skill proposed by authors from the motor-learning domain	Two- step or traditional approach	Four-step-authored by Walker and Peyton (Walker & Peyton, 1998)	Skill-teaching steps reported by the responders with a frequency of greater than 51% of the time
Stage one	Educator performs task analysis			✓
	Establish learner's prior knowledge and skill level			✓
Prior to teaching the skill	Pre skill conceptualisation of what the skill execution involves, looks, sounds, and feel like. Contra-indications of when not to perform the task are taught.			Question not asked in the SonoSTePs instrument
Stage two	Silent demonstration -learner observes		✓	X
	Demonstration-verbalisation of skill steps by the educator	✓	✓	✓
	Immediate error correction of learner's verbalised or executed skill steps			✓
The steps required to teach a psychomotor skill	Educator provides guidance and coaching			✓X
	Educator provides physical guidance			✓
	Learner verbalises the skill steps- prior to the educator executing the skill step (s)		✓	X
	Learner verbalises the skill steps prior to executing the step		✓	X
Stage three	Learner intentionally practices the skill.	✓	✓	✓
Skill practice and feedback	Educator provides post skill execution feedback			✓

10.10.2 Stage two of teaching of a psychomotor scanning skill

Stage two of teaching a psychomotor scanning skill involves the steps performed by the sonographer educator to demonstrate and teach the skill, and to provide immediate error correction while also limiting guidance and coaching when the learner is first acquiring and performing the psychomotor scanning skill (Nicholls et al., 2016a). The purpose of performing the skill demonstration is to provide a standard of performance, or what the skill should look like, and to convey the motor movements that are required to perform the skill (Fitts & Posner, 1967; Gentile, 1972; Schmidt et al., 2019). Less than half the respondents (46%) to this survey reported that they did not perform a silent skill demonstration of the scanning skill when they first taught the skill. A major finding of this research project was that 86% of respondents reported that they used an approach which involves demonstration and narration. A small number of participants (6%) reported that they did not teach scanning skills this way, while 8% sometimes used this approach. Similarly, less than half the cohort of responders (44%) stated that they asked the learner to describe the skill steps prior to the educator demonstrating the skill step. Less than half the cohort of responders 48% reported that they asked the learner to describe the skill step before the learner performed it.

The results of this study showed that most participants (79%) reported that they provided immediate error correction when they taught scanning skills. The provision of error-correction feedback involves making the learner immediately aware of all their verbalised or executed mistakes while the skill is being rehearsed and/or practised (Cornford, 1999; DeYoung, 2003). During the early stages of skill acquisition the creation of an error-free mental schema, or the motor program to execute the skill, is reliant upon the learner encrypting the motor map in their brain without mistakes (van Merrienboer & Sweller, 2010; Kantak & Winstein, 2012; Sattelmayer, Elsig, Hilfiker, & Baer, 2016). During this period, it is also important that the educator corrects all incorrectly narrated or performed skill steps as they occur, referred to as error-correcting feedback (Young et al., 2014). The provision of error-correcting feedback is essential as the learner does not yet have the ability to detect and/or fix their skill errors (Young et al., 2014; Sattelmayer et al., 2016).The corrective feedback maybe in the form of verbal instruction to the learner (Ong et al., 2016) or through the educator physically adjusting the transducer or the machine controls. Once the mental schema has been correctly encrypted into the brain, the motor map can then be recalled from long-term memory and executed without error or modified to suit the clinical practice (van Merrienboer & Sweller, 2010; Kantak & Winstein, 2012; Sattelmayer et al., 2016).

Guidance and coaching refer to the pedagogical approaches that provide sensory information to the learner, as the task is performed, about the motor movements needed to execute the skill. The sensory information may be in a verbal or non-verbal format (Ong et al., 2016). An example of verbal guidance is providing the learner with verbal cues about where to place the transducer on the patient to gain a better view of the organ. An example of non-verbal guidance is when the learner places their scanning hand over the educators as they scan together, referred to as tactile modelling (O'Connell, Lieberman, & Petersen, 2006). The purpose of this in-task feedback is to convey to the learner an understanding of the magnitude and combination of the motor movements used to perform an ultrasound; for example, the range of movements needed to sweep the ultrasound beam through the pelvis from one pelvis side wall to the other when performing a trans-vaginal ultrasound on a part-task phantom. The results of this survey show that the majority of the participants (92%) used guidance and coaching to support a learner's skill acquisition (see Table 10.6). This is the first time that this pedagogical approach has been reportedly used by sonographers when they teach a psychomotor scanning skill. It is unclear why this pedagogical approach is used by so many of the responders and further research is required to explore the role and application of this pedagogical approach. However, Ong et al. (2016) proposes, from the field of surgical education, that the use of verbal guidance and coaching communicates the motor movements to the learner that may have not been conveyed by the educator or perceived by the learner at the time of the skill demonstration.

Physical guidance, or hand-on-hand scanning, refers to the educator guiding the learner's hand as they hold the probe to get a better image of an organ (Dresang et al., 2004). The results of this study showed that 65% of the respondents reported using physical guidance to help learners acquire the optimal image of an organ or structure. The use of physical guidance alone, and coaching and physical guidance together, are instructional approaches that can be used to provide additional procedural knowledge about the motor movements needed to perform an ultrasound (Dresang et al., 2004; Sutkin, Littleton, & Kanter, 2015).

The importance of using physical guidance to teach psychomotor scanning skills was described over a decade ago. Dresang et al. (2004) published the first identifiable literature which acknowledged the use of physical guidance as a pedagogical approach to support the skill acquisition of family medicine residents learning prenatal ultrasound. Dresang et al. (2004) argues that hand-on-hand scanning conveys to the learner the transducer movements needed to obtain an image of the structures. At the same time, in the literature, Sonaggera (2004) pointed out that

sonography students valued having hand-on-hand scanning to direct them to the correct acoustic window or to convey the transducer movements that were needed to image the organ. However, Sonaggera (2004) does not use the term physical guidance to refer to this pedagogical approach. Brown et al. (2011), from a cardiac background, points out that transducer manipulation was one of the most difficult scanning skills to teach novices. Most educators have difficulty describing the large and small motor movements that were required to guide the transducer to obtain specific images of cardiac structures. Importantly, Brown et al. (2011) does not explain why these movements were a challenge to teach. However, Feygin, Keehner, and Tendick (2002), from a medical engineering background, assert that motor skills with three or more dimensions are difficult to explain and describe verbally (or even visually). This may explain why many sonographers use guidance, and coaching with physical guidance, to support a learner's skill acquisition. In fact, Dresang et al. (2004, p. 102) concludes that the use of physical guidance *" develops the learner's psychomotor skills in a way that observation, CD-ROM practice, and verbal instruction cannot* [and it] *appears to be an accelerator of learning"*. Similarly, Ong, Dodds, and Nestel (2016), from a surgical background, propose that physical guidance is a potent and adjunctive pedagogical approach to teach psychomotor skills. Physical guidance can provide the learner with kinaesthetic understanding of the type, timing, and magnitude of the motor movements required to execute the skill. Therefore, this study's results show that the use of guidance and coaching and physical guidance are two examples of the heuristic teaching approaches used by the responders to assist a learner's psychomotor skill acquisition and development.

Verbal coaching and physical guidance are forms of in-task feedback (Wulf & Shea, 2002; Leppink & van den Heuvel, 2015). This study has shown that 51% of the responders reported that they do not provide in-task feedback, even though 92% of the participants reported using coaching and guidance and 65% identified that they provided physical guidance as they taught scanning skills. These results suggest that the participants who responded to this survey may not know that these pedagogical approaches provide sources of in-task feedback. In-task feedback provides sensory information to the learner while they attend to practising and learning the psychomotor skill (Sigrist et al., 2013). Salmoni et al. (1984) asserts that when simple skills are being acquired and learned that the educator should limit in-task feedback to the learner, and only provide error-correcting feedback. The learner may become reliant upon the coaching to execute the skill. The result of the additional coaching is that the learner's skill performance improves but their long-

term learning of the skill may be undermined by the receipt of the feedback. The guidance hypothesis refers to the learner's enhanced skill practice as a result of receiving coaching, or in-task feedback, and this support may impede the long-term learning of the skill (Salmoni et al., 1984; Walsh et al., 2009). More recently, there has been considerable debate as to whether the learning outcomes and conclusions from using simple skills can be transferred to complex tasks (Sigrist et al., 2013). The prolonged provision of this educator feedback and support enhances the learner's skill performance, in the short-term, but degrades their long-term learning and recall of the skill referred to as the guidance hypothesis (Salmoni et al., 1984; Walsh et al., 2009).

White, Rodger, and Tang (2016), from a laparoscopic surgical background, argues that in-task feedback is required by the learner when complex psychomotor skills, such as performing laparoscopic surgery, are first being acquired and performed. The authors importantly point out that the feedback should only be provided in the early stages of the learner's skill acquisition and then faded. Fading feedback refers to decreasing the provision of feedback over time (Sigrist et al., 2013). However, White et al. (2016) does not elucidate precisely when the educator should commence tapering the feedback; therefore, the decision to fade the feedback is currently subjectively determined. In contrast, Bjerrum, Maagaard, Led Sorensen, Rifbjerg Larsen, Ringsted, Winkel, Ottesen, and Strandbygaard (2015) found that instructor feedback during proficiency-based laparoscopic simulator training did not affect the long-term retention of complex psychomotor skills by the learners. Thus, further research is required to gain an understanding of the type, amount, and frequency of the in-task feedback for those skills which are categorised as complex. Additionally, research is also required to determine the optimal time point to taper in-task feedback when the learner is acquiring a complex psychomotor skill. Finally, it is important to point out that there is very little research exploring the learning outcomes of using in-task feedback, and then fading the feedback, when learners are acquiring the scanning skills to perform an ultrasound examination. This is the first published study which reports on the prevalence of the use of in-task feedback to teach and learn complex scanning skills. However, this study did not explore the use and optimal point-in-time to fade in-task feedback.

10.10.3 Stage three of teaching of a psychomotor scanning skill

Motor skill acquisition is only achieved through skill practice and the receipt of feedback. Stage three of teaching a psychomotor scanning skill relates to the format selected for intentional practice (Ericsson et al., 1993) and the feedback approach that is used by the educator to

encourage the learner to reflect on their clinical practice performance, referred to as end-task or terminal feedback (Poole, 1991; Schmidt et al., 2019).

Deliberate skill practice (Ericsson et al., 1993) is essential to learn psychomotor, or scanning, skills (Sultan et al., 2013; White et al., 2016; Edwards et al., 2018).The skill practice format that is used by the learner will either advance or hinder their acquisition of the psychomotor skill. There is a small body of literature which suggests psychomotor skill acquisition is fostered through the use of more frequent and spaced practice sessions (Foy, 2009; White et al., 2016; Schmidt et al., 2019). The learner gains maximal benefit from practising the skill sub-part using multiple short practice sessions (Wulf & Shea, 2002; van Merriënboer et al., 2006; DeBourgh, 2011). The learner has multiple chances to encode the motor map for the skill and then to refine the schema with ongoing and variable skill practice. The results of this study have shown that 64% of the respondents use short skill practice session of less than 60 minutes duration.

There is some research to suggest that when the skill is complex the leaner benefits from practising the skill using session times that are shorter than 60 minutes in duration (DeBourgh, 2011; Kantak & Winstein, 2012). An example is laparoscopic surgery which involves the surgeon using complex psychomotor skills (Spruit et al., 2014). In the field of laparoscopy, short skill practice sessions were found to be superior for practising a complex skill when compared to using one long practice session of greater than 60 minutes (White et al., 2016). White et al. (2016), again from the discipline of laparoscopy, argues that when the skill is complex the learner gains very little benefit from practice sessions which exceed 45 minutes in duration. Whilst similarities can be made between the complexity of the psychomotor skills used to perform laparoscopic surgery and an ultrasound examination, it is important to point out that there is a lack of published research by the sonography profession on this topic in Australia and globally.

Longer skill practice sessions were reportedly used by 42% of the responders and an almost equal number of participants (41%) did not use long skill practise sessions. Some reasons which swayed an educator to support the learner practicing a scanning skill for 60 minutes or longer was evident in the open-text answers and stemmed from the educator not being able to provide the learner with skill practice opportunities earlier in the day. Limited scanning practice time is multifactorial and often outside the educator's control: for example, the patient was not well enough for the learner to scan them, the patient did not provide consent for the learner to scan them, or the department was busy and there were no practice opportunities for the learner. Consequently,

when a practice opportunity became available the educator encouraged the learner to practise their scanning for longer periods.

A learner's psychomotor skill acquisition is facilitated by the provision of end-task, or terminal, verbal feedback (Poole, 1991; Ericsson et al., 1993; Krause, Brune, Fritz, Kramer, Meisterjahn, Schneider, & Sperber, 2014; Schmidt et al., 2019). End-task feedback is also referred to in the motor-learning literature as knowledge of results (Walsh et al., 2009; Spittle, 2013; Schmidt et al., 2019). The verbal feedback should be based on the direct observation of the practice performance (Ende, 1983; Ramani & Krackov, 2012; Boud & Molloy, 2013). Effective feedback involves a two-way exchange of information between the learner and the educator. It should be based upon a standard of performance for the psychomotor skill (Molloy, 2009). The sonographer educator therefore has a role to facilitate the exchange of information between them and the learner. The outcome of facilitated learner-centred reflection on practise is the catalyst for the revision and change of a learner's clinical practice actions and behaviours (Molloy, 2009; Boud & Molloy, 2013; Kolb, 2015).

The survey results showed that the majority of the participants provide unidirectional information about the practice performance (i.e. from the educator to the learner). For example, a large majority of respondents pointed out what the learner did well (83%), identified what could be improved (81%), provided a summary of the skill performance to the learner (68%), and provided feedback at the conclusion of the practice performance (83%). These results suggest that the cohort were adept at providing directive and purposeful information about the practice performance to the learner. However, less than half the respondents reported that they, (1) asked the learner to provide an overview of the skill practice and state how they thought the skill practice went (47%, n=229/483), and (2) asked the learner to identify several aspects of the skill performance that they did well and why (47%, n=229/483).

There are many models which can be used by clinical health educators to provide end-task feedback to a learner about their clinical practice performance and 70% of the respondents reported that they do not deliver feedback using a feedback model. The Pendleton model is one approach that can be used to structure the format of the information exchanged between the educator and the learner (Pendleton et al., 1984). Although, it is important to point out that this model was not intentionally designed for the purpose of providing end-task motor skill acquisition feedback. Nevertheless, it is a model which has endured in the clinical space for several decades

and provides a framework and systematic approach which can be used to deliver feedback following a skill practice performance. The Pendleton model uses four steps to frame the content of the feedback to the learner (Pendleton et al., 1984). Step one, the educator asks the learner to identify what they did well. Next, the educator tells them what they did well. The third step requires the learner to identify areas of their clinical practice performance which could be improved. The final step requires the educator to also identify what areas could be improved and then to summarise the skill practice performance and create an action plan for future performances. The survey results show that the responders used two of the four steps that Pendleton et al. (1984) recommended: step two and four. More than half of the responders did not invite the learner to reflect upon their practice performance and follow by engaging in an exchange of feedback exchange with the learner. These practice steps are essential to the learner's continuing skill development and advancement.

The profession-specific findings about the one-way direction of feedback in the clinical environment, identified by these results, are not unique to the field of medical ultrasound imaging. In the discipline of physiotherapy, Molloy (2009, p. 134) found in her inaugural research on the tenets and practices of physiotherapist educators providing feedback to learners that the educators had a one-way 'conversation' with the learners which lasted approximately 21 minutes. Molloy (2009, p. 134) also found that the learner contributed to the 'conversation' for less than two minutes. The interaction provided unidirectional information to the learner and this was not a desirable outcome because the approach did not foster the learner to reflect on their skill practice. Therefore, one of the outcomes of the author's research was to suggest that targeted and profession-specific education and training was required to ensure that educators were aware of the role and purpose of providing feedback – that feedback must be a two-way exchange involve the learner to reflect on their clinical practice (Molloy, 2009). Molloy (2010) argues that there are three major benefits from providing end-task feedback to the learner, and they include: (1) students get the opportunity to self-reflect on their performance and gauge how they went, (2) the analysis and review of the practice performance helps to reinforce areas of good performance and identify practise areas for improvement, and (3) the feedback can be linked to the learner's future learning goal. The forward momentum of the feedback to improve future performances has been more recently described by Molloy (2010) as being forward feedback; therefore, is redefined as being feedforward information.

10.11   Dominant Skill-teaching Practice

The instructional approach which involves a skill demonstration and narration followed by supervised skill practise, is referred to in the literature as the master-apprentice skill-teaching approach or the two-step skill-teaching approach (Archer et al., 2015). The results of this study suggest that a two-step skill-teaching approach is being used by the sonography profession to teach psychomotor scanning skills. The majority of responders (86%) reported that they taught a psychomotor scanning skill by demonstrating the skill-steps and simultaneously describing the steps to execute the skill. The skill demonstration was followed by the learner practising the skill using short (64%) or long practice sessions (42%).

This study also found that the responders used other pedagogical approaches to support their teaching of psychomotor scanning skills. The instructional approaches that the participants used included: performing task analysis; establishing the learner's prior knowledge; providing physical guidance; using coaching and guidance, providing error correction; the facilitation of the learner's skill practice using mostly short skill practice sessions; and providing end-task or terminal feedback. Importantly, these results may also suggest that more than half of the responders (55%) are sometimes teaching the whole scanning skill in one teaching session. Therefore, the respondents may not be deconstructing the skill down into sub-parts and getting the learner to practice this part, before progressing to learning the next sub-part on these occasions.

One of the goals of using the two-step model is to provide the learner with a skill demonstration which serves as a mental model or standard of performance. However, the concurrent description of the skill steps as it is being demonstrated forces the learner to divide their attention between two sensory information sources, visual and auditory (Leppink & van den Heuvel, 2015). This activity may overload the capacity of the learner's working memory, consequently placing the learner into cognitive overload (Young et al., 2014). Importantly, when the two-step model is used to teach a scanning skill, the learner must also partition the sensory information into auditory and two visual foci of data. The learner is required to observe the educator demonstrate the transducer and image optimisation movements and also to observe the outcome of these motor movements on the ultrasound monitor. The complexity of this learning scenario is further compounded because the brain usually prioritizes the processing of visual information ahead of auditory information (Wise & Willingham, 2009; Spruit et al., 2014). In the setting where there are two forms of visual information being taught simultaneously, this forces the learner to focus on and attend to just one of the data sources. Therefore, it is recommended that the educator

performs a silent skill demonstration when they first teach the scanning skill (Walker & Peyton, 1998; George & Doto, 2001; Nicholls et al., 2016a). However, as a result, these new insights may also present a case for the educator providing two silent skill demonstrations when they teach a psychomotor scanning skill. The provision of two silent scanning demonstrations performed in succession allow the learner to first observe the motor actions performed by the educator to execute the scanning skill and then at the second demonstration to observe the corresponding ultrasound image for the skill. The educator plays an important role in this teaching setting by suggesting to the learner that they focus on different visual information at each of the silent demonstrations.

The primary goal of performing a skill demonstration is for the learner to get an idea of the movements that are needed to execute the skill (Fitts & Posner, 1967; Gentile, 1972). The assumption made by Fitts and Posner (1967) and Gentile (1972) is that *all* the motor movements that are needed to perform the skill will be visible at the time of the skill demonstration. At the time that these authors published their motor-learning theories and principles, health professionals were not using the sophisticated equipment that they currently use in clinical practice. Over the last four or so decades, there has been a need for health professionals from most disciplines to learn increasingly complex psychomotor skills to use and manipulate the equipment. Therefore, there is a need to revisit several of the tenets associated with learning a psychomotor skill published by Fitts and Posner (1967) and Gentile (1972). Sophisticated modern equipment frequently involves both upper limbs performing synchronous or asynchronous movements and concurrent observation of the outcome of skill actions. There is very little motor-learning domain literature and research which explores how complex bilateral upper limb psychomotor skills should be taught and learned (Schmidt et al., 2019).

Published skill-teaching models, for example the five-step model proposed by George and Doto (2001), Walker and Peyton (1998), and the 11-step model proposed by Nicholls et al. (2016a) also incorporate the need for the learner to view the skill being demonstrated three times. However, George and Doto (2001), Walker and Peyton (1998), and Nicholls et al. (2016a) specifically point out that the first skill demonstration should be performed silently. The provision of a silent skill demonstration allows the learner to observe the skill steps without dividing their attention between viewing the task performance and listening to the verbal narration of the learner (Young et al., 2014; Leppink & van den Heuvel, 2015). The practice of requiring the learner to simultaneously pay attention to acoustic and visual information is referred to as attention splitting

(Leppink & van den Heuvel, 2015). This practice increases the workload of working memory when the task is being initially observed (van Merrienboer & Sweller, 2010) and should be avoid when the task is complex. The second skill demonstration involves the educator repeating the skill demonstration while they describe the main skill steps. The third demonstration requires the learner to describe the skill steps in advance of the educator performing the corresponding step. In a more recent publication, Nicholls et al. (2016a) also stated that the learner should view three skill demonstrations when a complex skill is first being taught. However, none of the authors have provided the research or rationale to support why three skill demonstrations have been suggested to teach surgical skills (Walker & Peyton, 1998), advanced trauma and life support skills (George & Doto, 2001), and complex psychomotor skills (Nicholls et al., 2016a).

There has been an accepted assumption by health professional educators that the skill-teaching processes and theories proposed by many of the seminal motor-learning authors, for example, Fitts and Posner (1967) and Gentile (1972) convey through observational learning the motor movements needed to execute the skill. It is important to point out, that at the time these seminal motor-learning theories were published, sonographers had not yet commenced using dual upper limb concurrent tasks while they watched the results of these actions in real-time on a 2D monitor. Therefore, to advance the scholarship and understanding of how psychomotor skills are taught, acquired, and learned in the field of ultrasound, further profession-specific research is needed.

10.12   Sonographer Educator Interactions with the Student

A major finding of this research was that participants provided information to student sonographers at four points in time when they supervised the learner performing a psychomotor scanning skill. The four points-in-time that information was provided to the learner, included: before the examination commenced; during the ultrasound examination; prior to the patient leaving the department as the learner wrote up the examination worksheet and provided an interpretation of their scan findings; and at the end of the ultrasound examination. To my knowledge, this is the first time that these supporting clinical supervision practices have been formally identified and documented. The results of the content analysis of the open text responses showed that at each of these time points the educator was required to communicate with the learner differently and draw upon different bodies of knowledge to support the learner's clinical practice encounter. The skills to support this practice role differ from the clinical practice skills

needed to provide a safe teaching and learning environment as well as patient centred care. Bearman et al. (2011) describes the skill set which includes: professionalism, communication, collaboration, management, and leadership as non-technical skills. Non-technical skills are first taught and then learned, and they enable an educator to perform additional roles other than their primary role as a clinical educator.

10.13   Variable Teaching Approaches to Teach Student and Qualified Sonographers

The results of this study found that the majority of responders used different psychomotor skill-teaching approaches to teach student and qualified sonographers scanning skills. For example, 20 % (*n*=97/487) of responders reported that they did not change their teaching approach when they taught student and qualified sonographers a psychomotor skill. However, 21% (*n*=104/487) reported that they sometimes changed their teaching approach and the majority 59% (*n*=286/487) did not. Therefore, a large majority of the cohort used differing instructional approaches to teach learning and qualified sonographers. Open-text responses suggested that scanning skills were easy to learn for most qualified sonographers. There is a perception that qualified sonographers possess the unique and fine transducer manipulation skills needed to scan a new anatomical structure or when using a new device. However, the motor-learning theories on psychomotor skill acquisition challenge the ideology that qualified sonographers have the skill set to perform an ultrasound with no or minimal training.

The seminal motor-learning theorists propose that a mental schema or motor map must first be encoded, by any learner, before the skill can be recalled, modified, and executed (Adams, 1971; Schmidt & Lee, 2011; Kantak & Winstein, 2012). When the learner has not yet encrypted a motor map in their motor cortex, for the skill, they have no knowledge of the basic motor movements that are needed to execute the skill. When novel multi-planar transducer movements are first being acquired, by the sonographer, they must first be taught, learned, and then consolidated (Kantak & Winstein, 2012; Schmidt et al., 2019).

Research by Lavender et al. (2016) found that sonographers with variable skill proficiency required additional clinical skill education and training to be able to image the fetal corpus callosum in the sagittal plane using 2D imaging, at the 18-20 weeks gestational age morphology scan. The sonographers had not yet been taught the acoustic windows to image the fetal brain structure or the transducer movements to identify the fetal structure. Therefore, the research by Lavender et

al. (2016) provides the first identifiable evidence in ultrasound that supports the theoretical tenet that the creation of a mental schema is an antecedent step to be able to recall and execute the skill safely and efficiently.

10.14   The Variable Complexity of Psychomotor Scanning Skills

The survey results have shown that that ultrasound scanning skills vary in their skill complexity and that classifying the level of the complexity is currently arbitrary and self-determined. For example, respondents reported that when the learner was qualified and being taught a new scanning skill, most skills that were self-rated as being "easy" or not overly challenging were taught in one session. Examples of the skills which were less challenging and could be taught in one session included performing an ultrasound on a scrotum, a soft tissue mass, or a thyroid. The assertion by the respondents that scrotal scanning is easy is contentious and should be challenged. Pessin and Tang-Simmons (2017) found that acquiring the scanning skills to perform a scrotal scan was a challenge for novice operators. This is because the sonographer was required to perform multiples domains of clinical practice to perform the scan. For example, the sonographer had to overcome feeling awkward preparing the patient for the scan and examining the "palpable lump" (when present), being able to communicate with the patient appropriately, ensuring the anatomy was correctly scanned and that a diagnosis of testicular torsion was not missed. This example shows that performing an ultrasound examination is more involved than being able to perform the motor movements by each upper limb to complete the scan. In fact, it challenges the perception that performing a small part ultrasound examination is indeed an easy and uncomplicated examination.

In contrast, complex scans could not usually be taught in one session as there was too much theory and procedural skill knowledge to be taught at one session. Complex skills needed to be broken down into sub-parts and each part taught and practised separately. The skill parts were practised and progressively linked together until whole-task practice was achieved. Examples of complex skills included performing a cardiac scan and a morphology scan.

Essentially, the study results suggest that when the learner was a qualified sonographer, educators thought they could teach both simple and complex scanning skills in one session. However, this assertion is at odds with the cognitive load literature that explains the origins and teaching approaches that are needed to manage all learner's cognitive load.

Sweller (1993), followed by van Merrienboer and Sweller (2010), were among the first authors in the health professional education literature to introduce the concept that working memory had a finite capacity and that long-term memory had the potential to hold an unlimited supply of mental schemas. More recently, Sewell, Maggio, ten Cate, van Gog, Young, and O'Sullivan (2019) has pointed out that cognitive load theory is now a focal point in health professional education and in particular for those educators who are teaching psychomotor skills. Both van Merrienboer and Sweller (2010) and Sewell et al. (2019) posit that a learner may experience the effects of cognitive load from three separate sources. The first source, intrinsic load, refers to the cognitive demands placed upon the learner when they learn a complex task and they have nominal prior skill knowledge. The intrinsic load increases as the complexity of the skill being learned increases. The second source, extraneous load, occurs when learners' use working memory resources to attend to aspects which are not essential to the skill. An example is attending to distractions in the scanning room while scanning. The third source, germane load, occurs when the working memory is purposefully used to modify an existing schema (for example, to modify a scanning skill due to patient pathology) or to recall a number of skill schemas when random skill practice is scheduled (for example scanning the gallbladder, followed by scanning the aorta, and then obtaining the four chamber heart view on an adult). Sewell et al. (2019) outlines, in a scoping review, that all learners may experience the effects of cognitive overload when one, two, or all three of these sources of cognitive load are sufficiently large and they will overwhelm the learner. The author also makes a sobering and important point: it remains an ongoing challenge to fully grasp and understand the practical implications of cognitive load theory for health professional educational workplaces.

10.15 Teaching Beginning and Advanced Student Sonographers Psychomotor Scanning Skills

In the present study, the respondents used differing pedagogical approaches to teach scanning skills to novice and advanced student sonographers. In 2004, Sonaggera (2004) reported, from a survey of student sonographers, that novice and advanced sonographers have different learning needs when acquiring psychomotor scanning skills. Sonaggera (2004) found that novice sonographers preferred to observe the sonographer educator scan the patient before they scanned the patient. The present survey responses show 89% of the respondents reported that when they taught novices how to scan, they scanned the patient first, followed by the learner doing the scan.

Advanced learners have different teaching and learning needs when compared to their novice peers. The survey responses showed that when the responders taught advanced students scanning skills, 92% of the participants scanned after the student. Furthermore, this statistic showed very little variation across the differing specialist imaging cohorts. Sonaggera (2004) found that advanced students preferred to scan before the educator and then observed their teacher acquiring the images that they were either unable to get, or alternatively, that they sub-optimally imaged. However, Sonaggera (2004), provided no insights to explain why these results were found. One possible explanation for this learning preference is that the mental schema for the skill has not yet been encrypted with the psychomotor scanning skills required to image patients which altered anatomical variation or pathology. Therefore, the learner is not yet aware of these practice modifications which are required in these instances. Further research is required to understand the role that practice variation plays when the motor map is being encrypted for a given group of skills, e.g. for the schema variations which are required to image an anteverted, retroverted, and axial uterus.

10.16   The Use of Simulation to Teach Scanning Skills

The majority of respondents (83%) reported that they did not use simulation or simulative aides to teach scanning skills. The results found that most scanning skills are taught by the respondents in authentic clinical practice or on staff members, and 42% of respondents reported that they used their fellow staff members, or colleagues as scanning models to teach scanning skills – this is a form of simulated learning. However, using fellow colleagues to teach and practise the scanning skill, when the skill being taught is complex, may be unknowingly hindering a learner's psychomotor skill acquisition. With the use of simulation the learner gains an understanding of the motor movements to use to scan the patient without focussing on the additional dimension of scanning and interpreting complex pathology. Additionally, as the learner acquires and consolidates sub-parts of the larger skill, the educator can progressively introduce more and more complex skills, also referred to as scaffolding (Nicholls et al., 2016a). Sultan et al. (2013) argues that one of the major benefits of using simulation to teach psychomotor scanning skills – to anaesthetists – is that it provides one way for the learner to get an idea of the large and small scanning movements that are needed to move and manipulate the transducer. Crofts (2015), a sonographer educator, similarly concluded that when novices commenced scanning in simulation, they were unfamiliar with the magnitude and combinations of the large and small motor movements required to move and manipulate the transducer.

There are notable limitations to using mid- and low-fidelity simulative phantoms to practice some scanning skills, because many of them do not exhibit tissue perfusion (Pessin & Tang-Simmons, 2017). Pessin and Tang-Simmons (2017) found that testicular phantoms presented noteworthy clinical skill-teaching limitations when assessing tissue perfusion with Doppler or colour Doppler ultrasound. The authors concluded that when learners are acquiring the scanning skills to perform testicular ultrasound, on low-fidelity phantoms, that they are unable to practice the image optimisation scanning skills that are used to evaluate and document the presence of testicular torsion. This is because the phantom's organs are not perfused with arterial and venous blood flow. Yet, the diagnosis of testicular torsion relies on the absence of perfusion of the testicular parenchyma on colour Doppler imaging and on spectral Doppler. Consequently, educators are required to teach this skill using novel methods or alternatively on the job. There is a paucity of research and knowledge about the impact upon the encryption of the mental schema, or motor map, when skills are taught on low-fidelity part-task phantoms. This is because the sequence of motor actions required to perform the skill cannot be taught inclusively of the important and adjuvant skills, such as placing the colour Doppler box on the testis to confirm the presence of testicular blood flow.

A small percentage of the respondents (17%) identified they used simulation to teach scanning skills to students and qualified sonographers. These respondents wrote in open-text responses that there are instructional and learning benefits to being able to teach the initial scanning skills on simulative aides and not on a 'real' patient. The sonographer educator does not have to focus on the execution of three roles while teaching scanning skills on the job. The three roles included: delivering patient-centred care; being a gatekeeper of information to the patient and the learner; and providing sufficient teaching and learning opportunities and feedback to assist the progressive skill advancement and development of the learner. Gibbs (2014) also found that a major benefit of using simulation to practise scanning skills was the learner could focus on practising without concentrating on other aspects related to performing the task, such as communicating with the patient. There is limited literature to suggest that these insights proposed by Gibbs (2014) are both relevant and credible. Nicholls et al. (2018) also proposed that the co-occurring communication skills that accompany the execution of a psychomotor skill, on a conscious patient, should be taught to the learner after the psychomotor scanning skill set. Thereafter, both skill sets can be integrated until whole-task practice is achieved.

Simulation provides the opportunity for the sonographer educator to isolate the upper limb tasks and how and when they are taught. This ability to separate the tasks performed by each limb is reinforced by the findings of Crofts (2015) who identified that novices learning to scan struggled to combine the large and small motor movements that are needed to move the transducer to scan the structure. Crofts (2015) suggests that when educators first teach the initial scanning skills to a learner that they begin by scanning larger structures or organs to develop the understanding of the movements needed to perform a survey scan. Thus, the skill to initially move and manipulate the transducer, through the large and small motor movements, may be a more challenging and complex skill to learn than previously considered. Additionally, Crofts (2015) promotes an important concept related to the limitation of the finite capacity of a learner's working memory when they are first acquiring complex skills. It is important to point out that Crofts (2015) does not present her findings through the prism of the knowledge of the motor-learning theories and principles related to psychomotor acquisition. Rather, Crofts (2015) reported her observations of leaners, in the initial stages of learning scanning skill in simulation, and found that when the learner attempted to perform both upper limb tasks concurrently, they were unable to do so. In fact, the learner suspended scanning and performed the image optimisation and instrumentation with their console operating hand and resumed scanning after the adjustments were performed. The inability of the learner to perform two differing psychomotor skill sets concurrently raises the possibility that the learner has experienced cognitive overload (van Merrienboer & Sweller, 2010; Young et al., 2014). Thus, for learners to continue their skill practice they elect to perform just one skill set at this stage of their skill acquisition trajectory. With further skill practice and proficiency, space becomes available in working memory and when this occurs the learner is able to attend to other aspects of task practice (Spruit et al., 2014). An example of this is integrating both upper limb psychomotor scanning tasks while communicating with the patient (Nicholls et al., 2018) and/or other health professionals who maybe also involved in the execution of the skill.

10.17   Conclusion

This inaugural research has shown that Australian sonographers use a master-apprentice or two-step skill-teaching model to teach scanning skills. The survey results also show that there are instructional approaches that are being used by the participants to support a learner's initial acquisition of scanning skills which include: providing coaching and guidance as the skill is practised; performing physical guidance; providing immediate error correction; and providing end-

task feedback. However, most sonographers reported that they provided unidirectional end-task feedback to the learner, rather than a two-way exchange of information with the learner.

An additional finding of this research found that a learner's clinical performance is supported by the educator's verbal guidance and coaching which is given at four points in time throughout the continuum of the whole practice performance. These points in time include pre-task clarification, guidance, and practice norms; in-task verbal information and scanning support; post-task support and information; and end-task or terminal feedback.

The two-step model involves the sonographer educator first teaching the psychomotor scanning skill using a skill demonstration as they simultaneously describe the skill steps, and then the learner practices the skill. Using the two-step model may not be the optimal instructional approach to teach a complex scanning skill. There are three reasons why this approach may be suboptimal when teaching complex skills. First, using one skill demonstration may not visually communicate all the motor movements that are needed to perform the skill. Several skill demonstrations maybe required by the learner to communicate to them the sequence and magnitude of the large and small motor movements needed to perform the skill. Therefore, when only one skill demonstration is used by the educator, other pedagogical approaches maybe needed to ensure this procedural knowledge is known and understood by the learner. Second, the quantum of information that is concurrently taught when the skill steps are described and demonstrated, at the same time, may exceed the finite capacity of the learner's working memory and place them in cognitive overload. Third, the use of a narrated skill demonstration requires the learner to split their attention between two visual sources of information and the auditory information being simultaneously communicated and conveyed to the learner. This practice, when the skill is large and complex, may cause the learner to experience cognitive overload. The side effects of a learner experiencing cognitive overload include they take longer to learn the skill and their skill practice is punctuated with mistakes and is erratically executed.

This is the first published study which reports the prevalence of the use of these pedagogical approaches to teach and learn complex scanning skills. These results provide a corpus of new knowledge, and the first analysis and review, about the pedagogical findings related to teaching a psychomotor or scanning skills, required by sonographers, for clinical practice. Further research is required to establish whether the two-step skill-teaching approach is the best method to convey the motor movements required to perform a psychomotor scanning skill, or whether using

another pedagogical approaches, or combination of teaching approaches, will have improved long-term skill acquisition, learning, and retention.

The following chapter provides a review of the research strengths, weaknesses and the ongoing development of the SonoSTePs tool.

11 STRENGTHS, WEAKNESSES, AND LIMITATIONS OF THE RESEARCH

This next section chronicles the limitations of this body of inaugural research. An honest and transparent assessment of this project has been undertaken to ensure that the reader is cognisant of both the strengths and the limitations of the research, and the generalizability of the findings to the Australian population of sonographers. This chapter presents a review of the ongoing development of the SonoSTePs instrument and several recommendations for future improvements, prior to the instrument being used for further research.

11.1 Strengths of the Research Project

This project has several notable strengths and these strong points can be summarised as follows:

- The instrument was purposefully developed to measure the research question
- The instrument scales were written to represent the theoretical premises of the motor-learning literature to teach and learn a psychomotor skill
- The instrument progressed through a rigorous assessment of its items and the Likert-type rating scale
- The content of the instrument was formed using the critical review of sonographer academics and statisticians with an interest and expertise in survey design and psychometric assessment
- The instrument included open-ended questions which allowed valuable insights about the reported practice behaviours of the participants
- A census sampling approach was used to invite all sonographers registered with the ASAR to participate.

It was crucial that a purposefully developed survey instrument was created to explore the research topic. The instrument proceeded through an extensive development and validation process and two expert panel reviews. The SonoSTePs measurement tool was purposefully developed to explore the research topic. The survey items and rating scale items were specifically written to explore the theory, principles, and domains related to teaching a psychomotor skill. A review of the theoretical tenets to teach and learn a complex psychomotor skill were reviewed in Chapter 4. The items were written to align and represent the five identified theoretical scales linked to teaching a clinical or psychomotor skill and they included: teach new skill, visual exemplar, immediate skill error correction, cognitive overload, and skill practice. The final

sonographer skill-teaching practices survey, labelled SonoSTePs, is comprised of 25 questions, and three of these questions contained a total of 34 rating scale items.

A census sampling approach was used to invite participants to anonymously complete the online survey. The survey was completed by sonographers who practiced in all states and territories across Australia. The iterative development process required the Queensland responses to be used for the validation and therefore were excluded from the final results. Therefore, a final sample of 595 was achieved. This quantum of data should provide robust and reliable data about the skill-teaching practices and perceptions by Australian sonographers (Creswell, 2008). Creswell (2008, p. 156) suggests that when the number of responses exceeds 350 that the data set is representative of the broader populations' behaviours and perceptions. It is noteworthy to mention that the confidence intervals for the responses to the rating scale items are excellent, and suggest that the responses are representative of the practice behaviours of the broader population. However, several of the areas of dedicated ultrasound imaging may be under-represented due to small sample numbers, for example vascular sonography (n= 33 respondents). Therefore, when the data was analysed it was a strategic decision not to emphasise and focus on the differences in teaching approaches used by sonographers working in the different imaging areas, as a few of the cohorts had smaller sample number and progressing with individual sample analyses may have introduced non-response bias (Kumar, 2011; Sarantakos, 2013).

The content validity of the instrument items was established following two separate expert panel reviews of the instrument and two pilot tests. The SonoSTePs questions were modified and refined after P1 and the first expert panel's review. It was requested by a responder to the P1 survey that questions be included on the use of simulation to teach psychomotor scanning skills. This domain of enquiry had not been previously considered as an outright dimension of teaching a psychomotor skill. In response to this suggestion, several questions on this topic were included in the next iteration of the instrument. In retrospect and with the benefit of hindsight, after viewing the results, these questions were essential to include in the instrument. The first two SonoSTePs pilots and external reviews provided many suggestions to improve and the clarity, flow, and length of the survey. Importantly, these profession-specific suggestions were only gleaned from undertaking the two SonoSTePs pilot and expert panel reviews. Therefore, these steps reinforce the importance of establishing the content validity of the instrument. A further strength of this research has been the ongoing revisions of the instrument which have continued to improve the quality of the items and their representativeness to the research area. The culmination of a quality

instrument which provides reliable, credible, and valid data is an iterative and ongoing process which typically requires multiple reviews and modifications. The development and ongoing refinement of the SonoSTePs instrument is a strength of this research project.

The survey instrument also contained nine open-ended questions. Five of the questions were included in the last section of the survey which explored the participants' experiences as a learner and a teacher. Sarantakos (2013) points out that open-ended questions provide the opportunity to gather additional insights which may have been excluded by using only closed questions. The results of this research have shown that valuable insights and unexpected findings have been garnered from the use of open-ended questions. Furthermore, the results from the content analysis have provided rich and unexpected data about the complexity and consideration of multiple factors that are experienced by educators when teaching psychomotor scanning skills on the job in busy departments. These insights would not have been garnered if closed text and rating scale questions were used exclusively in the SonoSTePs instrument. In the final section of the instrument, an important teaching approach was deliberately explored using a rating scale item and then with the use of an open-ended question. The analysis of the results showed that the number of respondents who reported that they did teach the whole scanning skill in one session was almost identical for each question. However, the results differed for the number of responses who sometimes or did not teach the whole scanning skill on the one session. Further content analysis of the 216 open-text responses provided additional data which suggested that many sonographers did teach a scanning skill in one teaching session and that their reasons for these behaviours were complex, interconnected, and multifactorial. The use of open-ended questions has been invaluable in this research project. The responses to the open-ended questions have provided another form of evidence and this data has been able to be used to challenge the validity of the accuracy of the respondent's answers to an important rating scale question. The limitations of self-reported data are well known and have been previously described in the literature (Creswell, 2008; Molloy, 2009). The results of this research have shown that one use for open-ended questions is to provide another type and form of data which can then be used to analyse and contrast the voracity of the results obtained from a rating scale question which explores the same practice behaviour.

Rigorous psychometric assessment of the SonoSTePs instrument has been essential to characterise the instruments strengths and weaknesses. The psychometric assessment of the instrument properties revealed the latent strengths and weaknesses of the instrument. For

example, following the P1 assessment of the instrument, it was found that using a five-point Likert rating scale provided poor discriminant ability; consequently, a seven-point Likert rating scale was used for the P2 assessment. Statistical analysis of the discriminant ability of the seven-point Likert rating was greatly improved and this rating scale was used for the remainder of the research project. The psychometric testing of the SonoSTePs P3 instrument was further advanced to statistically assess how well the items in the rating scale 'hung together' and represented the research topic. Exploratory factor analysis was undertaken and showed that the questions within the item pool related to a four-factor model, and the statistical analysis of the items found that each factor had good internal reliability, represented by Cronbach's alpha. The test-retest of the instrument also established that the instrument items were stable after the re-test assessment, over a quantified period of time. Following statistical analysis of the national SonoSTePs items, the items once again show good reliability and that they relate to a four-factor model (see Appendix 9).

A major limitation of the previously published ultrasound skill-teaching research, outlined in the literature review, was that the sample numbers used in most projects were very small (less than 10 participants) and the described methodology did not enable the research to be replicated. Therefore, a major goal of this research was to avoid these notable and reported limitations. A census sampling approach was used to invite all qualified sonographers who were registered with the ASAR to anonymously complete the online survey. The decision to use the ASAR was strategic as the ASAR was the only data base in Australia where *all* sonographers were compulsorily required to be registered. In contrast, membership to other professional organisations, for example, the ASA or ASUM, was not compulsory and consequently, if either organisation had been used to distribute the survey this would have knowingly introduced response bias.

11.2   Limitations

As with all research, this study has several limitations. These include the response rate, the reliance on self-reported data, the exclusion of the Queensland cohort from the final analysis, a retrospective test-retest assessment of P3.

The overall response rate to the SonoSTePs questionnaire was low (19%) but is consistent with other online survey response rates. Raffi et al. (2012, p. 2717) found that the response rate to online surveys using 'SurveyMonkey' varied between 8% and 36%. In this present work, the response rate to the survey was 19% and consequently did not provide strong reassurance that

important data had been collected due to non-response bias (Sarantakos, 2013). However, the confidence intervals for the responses to the rating scale items suggest that the responses are representative of the practice behaviours of the broader population. Therefore, the true impact and implications of the 19% response rate may not have the visceral impact upon the results when the sample number is greater than 350 (Creswell, 2008, p. 156), and the confidence intervals suggest that they are representative of the broader population. However, this response rate resulted in a reduced capability for any statistical analysis of sub-groups, such as based on role or qualifications, simply because the numbers in sub-categories were too small and the distributions too varied for meaningful analysis.

The results of this research have relied upon self-reporting data. There are known limitations to relying on self-reporting data (Creswell, 2008; Molloy, 2009; Sarantakos, 2013) when there has been no independent verification of the participants reported skill-teaching behaviours and practices. Molloy (2009) established that the reported clinical feedback practices of a small cohort (n=18) of physiotherapists to a survey were different to the actual pedagogical practices used by the educators in clinical practice. The disparity in the actual and reported clinical practice behaviours was only identified after video evidence of the physiotherapists' clinical practice encounters was captured and then analysed and compared with the survey responses. Indeed Molloy (2009, p. 129) stresses the importance of ensuring that research method includes triangulation of the data and that data is obtained from the clinical educator, student, and observational data to ensure the integrity and authenticity of the results. This point of view is substantive for those research methods which focus on using a qualitative approach and also use small sample numbers. However, this present study used a census sampling approach with 4460 potential participants. Triangulation of data in this approach was not feasible.

Creswell (2008, p. 266) states that "triangulation is the process of corroborating evidence from different individuals… types of data…. or methods of data collection". This project was framed by a post-positivist grand theory and the associated research method was biased towards capturing quantitative data, while the interpretivist approach captured qualitative data through the use of open-text questions. The analysis of the open-text responses provided additional and important information about the perceptions and behaviours of the responders which would not have been gleaned through the use of rating scale questions alone. Additional information about the skill-teaching practices of the educators may have been obtained by undertaking a pilot study, using qualified and student sonographers, to explore the integrity and authenticity of these results by

conducting semi-structured interviews or capturing video evidence of sonographer skill-teaching practices. However, the logistics of obtaining a representative and large enough cohort from each group was impractical.

The Queensland sonographer cohort were integral to the research process as their responses were used to perform the P3 initial validation, determine the psychometric properties of the instrument, used in the retrospective test-retest analysis of the instrument, and then determined the temporal reliability of the instrument. The exclusion of the Queensland cohort may have influenced the quality and the representativeness of the final national data. There are two universities in Queensland that offer courses to gain sonographer credentialing in ultrasound and one private teaching institution that provides scanning programs for a variety of health professionals. Each of these institutions employed credentialed and experienced educators who teach scanning skills. A total of 142 sonographers from Queensland completed the P3 survey. It is unclear if the exclusion of this cohort from the national survey results has impacted on the representativeness of the data garnered from the remaining national cohort of sonographers. The confidence intervals, again, indicate that this is probably not a major issue statistically.

The SonoSTePs instrument questions changed between P3 and conducting the national survey. Therefore, the temptation to merge or create a hybrid data set based on the total number of sonographers who completed common questions in both instruments was abandoned due to the varied data set combinations and the tenuous outcome of being able to generate substantive and meaningful results.

Following the completion of the national SonoSTePs survey, the test-retest analysis of the P3 SonoSTePs was retrospectively conducted with those sonographers practising in the state of Queensland. There were two important reasons why it was incorrect to have performed the psychometric assessment of the SonoSTePs instrument at this time in the research. First, the purpose of undertaking a survey test-retest assessment is to determine the temporal stability of the instrument. The statistical information has maximum relevance and psychometric application when the instrument development has been completed. In other words, no further changes will be made to the rating scale items. However, in Chapter 9, it was reported that between conducting the P3 SonoSTePs research and the national SonoSTePs survey, the rating scale instrument items were further culled and refined. As previously discussed, these changes were essential to the ongoing refinement of the instrument. Therefore, to have undertaken this

retrospective assessment at this time served little purpose because the instrument was still progressing through further development. What the test-retest result showed was that the P3 version of the participant's responses to the instrument were stable over two time points. Therefore it is a recommendation of this research that following the production of a stable and final version of the SonoSTePs instrument that another test-retest is performed (Creswell, 2008; Sarantakos, 2013).

As a result of the survey and additional understanding of this research topic, further changes are required to the SonoSTePs rating scale items to ensure that the instrument items are truly representative of the research topic. This is important before the SonoSTePs instrument is used to sample other professional cohorts of ultrasound operators.

11.3 The Ongoing Statistical Assessment of the SonoSTePs Instrument and Refinement of the Instrument

Following the national SonoSTePs survey, the survey data was analysed to explore whether the revised instrument items continued to represent the five theoretical domains that are related to teaching a psychomotor scanning skill. A multiple approach model for factor extraction was used, consisting of principal component analysis, Kaiser's criterion (eigenvalues >1.0), scree plot and parallel analysis, to simplify and reduce the items into factors and then determine the number of factors to be retained (Tabachnick and Fidell, 2007). The scree plot in Appendix 9 suggests that there are 5 factors with an eigenvalue >1; therefore, the items represent five factors. Horn's parallel analysis (see Appendix 9) was used to determine the number of factors to retain within the items pool, and this step preceded performing EFA. When the resultant parallel analysis plot was transposed over the Cattell scree plot there were four clear factors which lay above the juncture of the two graphics. This suggests that four factors were to be extracted from the item pool. Cronbach's alpha was used to explore the strength of the relationship of each item to the factor (Tabachnick & Fidell, 2007). Oblique direct-oblim rotation was used to further simplify the factor structure (Williams et al., 2010). Exploratory factor analysis generated a pattern matrix for a four-factor model (Appendix 9), suggesting that there are four domains or scales that are related to the research topic. Therefore, the 34-item rating scale used for the national SonoSTePs survey are related to four statistical domains of enquiry and the Cronbach's alpha for the 34 items was 0.85. A Cronbach's alpha of 0.7 or above is an acceptable value for scale reliability (Johnson & Christensen, 2012; De Vellis, 2012).

There are five theoretical domains identified in the literature which relate to teaching a psychomotor skill. It is a recommendation of this research that the SonoSTePs instrument items are not reduced to correspond to a four-factor model, as it is not clear whether the results of EFA have been influenced by the skill-teaching literacy of the respondents who completed the survey. This knowledge about the literacy of the cohort of responders who completed the survey only became known following data analysis of the SonoSTePs survey results.

11.4   Further Changes to the SonoSTePs Rating Scale Items

Further refinements to the questions and rating scale items were required following a review of the results of the national SonoSTePs results. For example, it was an oversight not to have asked, in the previous versions of the SonoSTePs survey, a question about whether the theoretical knowledge, indications, and contraindications are taught before the skill is physically taught or at the same time it is taught. In the revised instrument, question 14B was added to the rating scale items and asked, "When teaching a sonographer an ultrasound scanning skill, do you: teach the theoretical knowledge to support the skill execution prior to physically teaching the skill?" This was been added because the motor-learning domain literature suggests that the volume of information provided to the learner when the theory is taught at the same time as the psychomotor skill will probably exceed the capacity of the learner's working memory and cause cognitive overload (van Merrienboer & Sweller, 2010). An additional question was further recommended to clarify what pedagogical approach is used to teach the theory related to performing the psychomotor scanning skill, the indications and contraindication about when and when not to perform the skill, and the care and disinfection of the equipment. Question 22 in the revised instrument (see Appendix 10) explores this area of enquiry and asks, "Prior to teaching a scanning skill do you teach the theoretical knowledge, related to the execution of the scanning skill, using a didactic lecture format?" After which the person selects either yes, no, or sometimes, and is then asked to briefly explain why. Also, the clarity of question 14J in the revised instrument has been further refined to explore whether the guidance and coaching includes verbal information. Therefore, the word 'verbal' has been added to the question and the revised question is, "Do you when teaching a sonographer an ultrasound scanning skill provide verbal guidance and coaching during skill performance?' The addition of the word 'verbal' removes any ambiguity about whether the educator provides verbal or physical guidance and coaching during the skill performance.

After the retrospective review of the P3 instrument, it was unfortunate to have removed question 14D. This question explored whether both upper limb tasks were taught at the same time. The question asked, "When teaching an ultrasound scanning skill, do you: when teaching a new skill to a beginning student, do you teach how to perform the scan, patient positioning and image optimization in one teaching session?" This question is verbose and lengthy and Sarantakos (2013) points out that the use of long questions should be avoided to improve the clarity of the question. Consequently, the proposed question 14B in the revised instrument asks, "When teaching a scanning skill on a patient or imaging phantom, do you: teach how to position the patient, select the acoustic window, scan and perform the necessary image optimisation in the one teaching session?"

Following the interpretation of the results of the national SonoSTePs survey, it is suggested that an open-text question is included in the main body of the survey to explore why phantoms are or are not used to teach psychomotor and scanning skills. However, to introduce this question, question 10 will no longer be pre-set as a 'skip question' after the respondent answers 'no'. The additional question would ask, "You have identified that you do not use simulative learning models to teach scanning skills. What are the mains reasons that you do not use simulative learning tools/models to teach scanning skills? Response options could include: 1) the purchase cost of phantoms or simulative aides, 2) the cost to hire a simulated patient is expensive and unaffordable, 3) the department cannot get funding to purchase a simulative teaching tool, 4) the simulative teaching tools do not provide value for money as they need to be replaced every 5-10 years, 5) I have not considered this an option for the department, and 6) I do not know how to teach scanning skills on a phantom so I have not purchased a simulative aide. An open-text box to the following extension of this question is suggested. Asking the respondent "Please provide additional information if the above responses have not been able to solicit why you do not teach scanning skills using a simulative learning tool". An open-text box could seek further descriptive explanations.

Finally, there are 11 rating scale items in the SonoSTePs instrument which explore multiple aspects related to the provision of feedback. In the national SonoSTePs instrument, question 15 explored whether the responder provides feedback at the conclusion of the practice performance. Question 15 asked, "When teaching a clinical skill to a sonographer, do you provide verbal feedback (information) on their performance of the skill? A) Yes, B) No - I work as a solo sonographer, C) No - I do not know how to give feedback on skill performance, and D) No - I prefer not to be involved with giving feedback and guidance to my colleagues or students". Statistical analysis of the

responses to this question did not provide additional perceptions about the responders practice behaviours that had not already been gleaned from the responses to the rating scale questions. Therefore, in the revised SonoSTePs instrument this question could be removed, as redundant questions provide no further information on the research topic and unduly add to the effects of survey fatigue (Kumar, 2011). Following these revisions, additions, and exclusions the revised version of the SonoSTePs instrument is now comprised of 26 questions. Three of the questions now contain a total of 36 rating scale questions; as, two extra questions were added to the item pool after the review of the national SonoSTePs survey (see Appendix 10). This version of the instrument requires further validation.

The following chapter, the conclusion, briefly reviews the outline for the research project, and then provides a short synopsis of the overview, context, and scope of the research project. The research question and problem will be reviewed. A short review of the methodology will be provided and an explanation of how the results of the literature review helped to frame both the scope of the research and the research methodology used. Thereafter, the theoretical, methodological, and practical contributions of this body of inaugural work will be presented. Finally, the recommendations and significance of this body of work will be reviewed and described.

12 THESIS CONCLUSION

The following chapter, the conclusion, briefly reviews the outline for the research project, and then provides a short synopsis of the overview, context, and scope of the research project. A review will be made of the research question, the problem, the methodology, and how the results of the literature review have helped to frame the scope and research methodology. Next, the theoretical, methodological, and practical contributions of this body of inaugural work will be presented, highlighting its original contribution to knowledge. Finally, the recommendations and significance of this body of work will be reviewed and described.

12.1   A Profession in Rapid Evolution

Medical ultrasound imaging began from humble beginnings in Australia, in the 1960s, and has rapidly advanced over the following decades. Throughout this period, the design and imaging capabilities of the equipment have changed at an extraordinary rate. High-end equipment offered cutting-edge imaging technology which was smaller, more portable, and affordable. Operators of medical ultrasound equipment now need to be able to execute sophisticated and multidimensional psychomotor skills by both upper limbs, to be able to optimally use and operate an ultrasound machine. This skill set was not required when ultrasound machines first entered the clinical space in the 1960s, nor for a further decade or more.

There was a limited role for the operators using the first generation of ultrasound machines in Australia because the movement of the transducers was mechanised. The operator did not need to perform image optimisation and instrumentation functions at this time. However, subsequent technological advancements required the users of the machines to learn a new and limited upper limb skill set. With the continued technological, computer, and imaging advancements, more sophisticated scanning skills were required to use and operate the equipment. The advent of handheld transducers which could be moved in any plane and any combination of arcs and angles required sonographers to learn a new compendium of psychomotor scanning skills. During the initial 15 years that ultrasound was used in Australia, just a few sonographers, medical scientists, and doctors became skilled at using the equipment and interpreting the images. These operators would later become the pioneers of the profession and taught others how to use the equipment.

The advent and evolution of ultrasound in Australia has shaped and influenced how psychomotor scanning skills were taught for many decades. This is because there is anecdotal evidence that a

small number of learned experts taught other less-experienced operators the theory and practice knowledge to be able to scan. This skill-teaching precedent was established during these formative years of the profession, and it was speculated that it has endured through to the twenty-first century. The practice of an expert demonstrating and describing the scanning skill steps followed by the learner practising the skill refers to the master-apprentice or the two-step skill-teaching model (Archer et al., 2015). However, there was no theory or practice evidence for how these scanning skills were being taught. There was a notable absence of research about the science of teaching these skills in Australia and the world. The dearth of research precluded a critical review and analysis of the skill-teaching approaches being used by sonographers in clinical practice.

12.2   Outlining the Research Aims and Objectives

The aim of this inaugural body of research was to gain an understanding about how psychomotor or scanning skills were being taught in clinical practice by Australian sonographers. In particular, the research project had four objectives: 1) to conduct the first profession-based research which explores Australian sonographer psychomotor skill-teaching practices using a survey instrument; 2) to determine whether a master-apprentice skill-teaching approach, or two-step model, is used by sonographers to teach psychomotor scanning skills; 3) to identify whether the profession uses heuristic instructional practices to teach psychomotor scanning skills; and 4) to summarise the pedagogical approaches used by the profession to teach psychomotor scanning skills, and to compare these teaching practices with the pedagogical approaches that have been suggested to teach complex psychomotor skills.

12.3   A Brief Review of the Thesis Chapters

A literature review was undertaken at the outset of the project in mid-2012 and two papers were retrieved, and additional one was identified by the end of that year. The paucity of retrieved literature provided the reassurance that the topic had not been research previously. The lack of literature also meant that a novel and pioneering research project was required. To commence this research project, the term 'psychomotor skill' needed to be defined. This term stood for a broad skill set that was being used by the sonography profession, and indeed other users of ultrasound imaging. The compendium of skills used to perform an ultrasound had not previously been associated with the term 'psychomotor scanning skills'. The skill set used by operators of ultrasound imaging equipment were described in a peer-reviewed paper in Chapter 2, titled "Psychomotor skills in medical ultrasound imaging: an analysis of the core skill set". This paper

presented new knowledge about the depth and breadth of the skill set that is used by sonographers to perform an ultrasound examination. It also presented for the first time, in the published literature, that the psychomotor skills used by sonographers are multi-dimensional and multi-part; therefore, many of the scanning skills used by sonographers are an example of a complex psychomotor skill. Psychomotor skills used by health professionals can be classified as either simple or complex. Yet, there had been very little specific health professional literature which had published a method to classify a psychomotor skill. In Chapter 3, the rationale for classifying a psychomotor skill was presented alongside a process to categorise the skill as being simple or complex. This step was important for two reasons. First, health professional educators can classify a psychomotor skill using this classification process, and then compare the results from using a pedagogical approach for skills of similar skill complexity. Second, the educator can classify the skill before they begin teaching the skill. This is an important step to undertake for educators teaching psychomotor scanning skills, especially since a small number of authors suggest that the pedagogical approaches used to teach simple and complex skills differ (Wulf, Shea, & Matschiner, 1998; van Merriënboer et al., 2006; van Merrienboer & Sweller, 2010; Wulf, Shea, & Lewthwaite, 2010; Sewell et al., 2019). This is the first time in the health educational literature that a classification method has been proposed to categorise psychomotor skills before they are taught. Using the classification system will enable educators to use a pedagogical approach that is suited to the skill complexity. Furthermore, the research outcomes from using differing pedagogical approaches can then be accurately compared for a given level of skill complexity. This proposed method of psychomotor skill classification, for health professionals across all disciplines, provides an original contribution to knowledge. In Chapter 4, the seminal motor-learning theories were reviewed and critically analysed in a peer-reviewed paper titled "Teaching psychomotor skills in the twenty-first century: Revisiting and reviewing instructional approaches through the lens of contemporary literature". Following this review, an 11-step skill-teaching model to teach complex scanning skills was proposed. The model included the essential steps needed to support the teaching and learning of a complex psychomotor skill. There is also a need for the sonographer or operator to communicate with the patient when they are performing psychomotor scanning skills on an awake patient. However, the 11-step model did not explore how the co-occurring communication skills which accompanied the skill execution were taught. Communication skills have been identified as being an essential component of an entry level sonographer's professional practice by the ASA (2011). Despite this, there were no published guidelines or steps which support the educator to teach communication skills as a psychomotor skill was being acquired. In

Chapter 5, the literature to teach communication skills was reviewed and a seven-step model was proposed to teach the communication skills that accompany a sonographer performing a psychomotor skill. The published peer-reviewed paper is titled "A model to teach concomitant patient communication during psychomotor skill development". The paper importantly points out that the learner should become familiar with the skill steps to execute the task and the sensory norms that the patient will feel or encounter as the skill steps are performed, notably before the co-occurring communication skills are taught. In Chapter 6, a scoping review of the relevant literature related to teaching a scanning or psychomotor skill was undertaken. Following the initial review, the next iteration of the review was expanded to include other cohorts who teach and use scanning skills in their clinical practice, for example, anaesthesiology, emergency medicine, and paramedics. The results of the literature review suggested that no single definite skill-teaching approach was used by most educators to teach scanning skills; however, the two-step model was used in several studies to teach psychomotor scanning skills. The review found that there had been no publications in the English language which had previously explored this research topic. Chapter 7 presented the research design, method, and rationale used to answer the research question. A cross-sectional survey design approach was selected as the method to explore this research topic using a purposefully developed and validated survey instrument to measure sonographer skill-teaching practices and perceptions in clinical practice, labelled SonoSTePs. In Chapters 8 and 9, the steps used to construct, develop, refine, and validate the survey content were explained. The literature review which was undertaken to write Chapter 4 had also identified the five main scales, or domains, that related to teaching a complex psychomotor skill. The survey items were purposefully written to align with these identified motor-learning theories and principles and to also explore the depth and breadth of these five theoretical areas scales. As described in Chapters 9 and 11, the psychometric properties of the instrument were calculated, and these statistics suggested that the instrument questions were measuring what they intended to measure. These calculations provide the evidence that the instrument was collecting data that was reliable and valid data. In Chapter 10, the study results from the national sonographer survey were presented after undertaking a cross-section design survey approach of the reported skill-teaching practices of 592 sonographers located across Australia. In Chapter 11, the strengths of the research, the limitations, and the ongoing development of the SonoSTePs instrument were reviewed and chronicled. Finally, in this concluding Chapter 12, the major findings of the research and the original contribution that this research makes to the science of how the sonography profession teaches psychomotor scanning skills is presented.

12.4   Outlining the Research Approach Used

This study used a post-positivist research approach to explore the skill-teaching practices of Australian sonographers. The post-positivist paradigm involves developing evidence about a research topic while acknowledging that elucidating all the facets related to the research topic may prove to be challenging because the topic area is complex and that the results are frequently context dependent (Cleland & Durning, 2015) This approach enabled data to be obtained from a large sample of the sonographer population with the intended outcome being that the results could be extrapolated to the broader population (Creswell, 2008).

A search of the literature did not identify a survey instrument which could be used for this research project. Therefore, the sonographer skill-teaching practices survey, labelled SonoSTePs, was purposefully developed and validated over an 18-month period. The instrument development was guided by the principles of survey development proposed by De Vellis (2012) and the nine-steps to create a survey posited by Sarantakos (2013). Using the nine-step model proposed by Sarantakos (2013), the online instrument proceeded initially through two pilot tests, two external reviews, a then a third pilot to determine the psychometric properties of the instrument. Between the first and second pilots of the instrument the rating scale was changed from a five-point Likert rating scale to a seven-point Likert-type rating scale to improve the discriminant ability of the instrument to discern and record the teaching practices and behaviours of the respondents. Sonographers practicing in Queensland were the sample cohort used to undertake the P3 assessment of the instrument. Following the P3 survey data analysis and psychometric testing of the rating scale items, it was found that the items related to four factors associated with teaching a psychomotor scanning skill. Additionally, the reliability of the instrument items was calculated to be good. Nevertheless, a critical review of the instrument items identified that further refinements were required to many of the instrument rating scale items to improve question clarity (see Chapter 9 for a detailed review). The final version of the SonoSTePs instrument used for the national survey of the sonographers was comprised of 25 questions. Three questions contained a total of 34 rating scale items which explored the five theoretical domains or scales related to teaching a psychomotor skill.

A census sampling approach was used to ensure that data was collected from a large and representative proportion of the population. All sonographers registered with the ASAR in late 2014 (n=3151) were invited to participate in the research. Invitation was by email and the survey remained open for 11 weeks with three reminder emails sent to the potential participants.

12.5   Summary of Major Findings

A total of 592 sonographers completed the survey, giving a response rate of 19%. Overall, the results of this research have shown that nearly all the respondents used a skill-teaching approach which involved the educator providing a narrated skill demonstration and then the skill being practised by the learner. At least two thirds of the participants encouraged the learner to practise the skill using short skill practise sessions. Teaching a scanning skill using an approach which involves the educator performing a narrated skill demonstration followed by the learner practising the skill is referred to as the master-apprentice or two-step skill-teaching model (Archer et al., 2015).

12.5.1 The two-step skill-teaching model

Using the two-step model to teach a complex psychomotor skill has four instructional and learning limitations. First, one skill demonstration may not communicate, or convey, all the motor movements that are needed to execute a complex psychomotor skill. Next, demonstrating the skill while the educator provides a narration of the skill steps requires the learner to split their attention between the two sensory sources of information (Leppink & van den Heuvel, 2015) and this should be avoided. Following on, the volume and differing types of information (theoretical and procedural) that are taught in a teaching session may be too large; consequently, the learner may experience cognitive overload (van Merrienboer & Sweller, 2010; Young et al., 2014; Sewell et al., 2019). Finally, using the two-step model to teach a psychomotor skill does not require the educator to provide end-task feedback to the learner. These limitations will be reviewed in the following sections.

12.5.1.1 *Visual exemplar*

A visual exemplar enables the observer to get an idea of the motor movements needed to execute the skill and serves to provide a visual exemplar of the skill performance. A visual exemplar should portray the correct sequencing, timing, and motor-skill actions that are needed to execute the skill. Using the two-step model to teach a psychomotor skill does provide the learner with a skill demonstration and the majority of the respondents used this approach to teach psychomotor scanning skills. However, most psychomotor scanning skills are complex; they are multi-part and each part requires a sequence and combination of large and small motor movements to be executed. Therefore, the use of one skill demonstration may not convey to the learner the gamut of these motor movements that are needed to perform the skill. Therefore, further research is required to determine how many of the motor movements are perceived by the operator when

the two-step skill-teaching model is used to teach psychomotor scanning skills. Additionally, further research is required to establish how many skill demonstrations maybe needed for the learner to perceive the majority of the motor actions needed to perform an ultrasound. This is because the model proposed in Chapter 4 suggests that the educator should provide three skill demonstrations followed by the learner executing the skill, when it is initially taught. However, there has been no profession-specific research to explore whether this 11-step model is superior to the two-step model for the teaching and learning of scanning skills.

12.5.1.2 *Attention splitting*

Using the two-step approach to teach a complex psychomotor skill requires the learner to pay attention to the educator providing a visual skill demonstration and a verbal rendition of the skill-steps concurrently, as the skill is taught. Sonographers are also required to pay attention to the ultrasound monitor as this provides a real-time outcome of what the skill looks like. Therefore, using the two-step model to teach scanning skills requires the learner to split their attention between two visual sources of information and one verbal source. Using the two-step model to teach a psychomotor scanning skill requires the learner to choose which form of sensory information they are going to focus their attention on. This task becomes further complicated for novices as the brain prioritizes visual information ahead of acoustic information (Sigrist et al., 2013). There is very little research which has explored which visual source the learner focuses on when there are two competing visual sources which are of equal importance to the learning outcome. Considering this analysis and having garnered further understanding of this area throughout the duration of this research, it is proposed that two silent skill demonstrations may be required when first teaching each of the upper limb scanning skills. One demonstration is provided to enable the learner to observe the range and magnitude of the motor movements. This is followed by replicating the demonstration to enable the learner to observe what the skill looks like on the ultrasound monitor. Therefore, it is now proposed that the 11-step model should be extended to include 12 instructional steps when ultrasound scanning skills are taught. The additional silent demonstration provides the learner with the opportunity to focus on just one of the visual foci of data at any one time.

12.5.1.3 *Cognitive load*

Learning a complex psychomotor skill places large demands on a learner's attention and is cognitively demanding (van Merrienboer & Sweller, 2010; Sigrist et al., 2013). Using the two-step model to teach a scanning skill requires the learner's brain to simultaneously process a large

amount of sensory (acoustic and visual) information at once. When the skill is new, an adults working memory may struggle to cope to process with the volume of information provided to the learner at once, and this practice results in the learner experiencing cognitive overload (Sweller, 1993; van Merrienboer & Sweller, 2010; Sewell et al., 2019). When a learner experiences cognitive overload their skill acquisition trajectory is impeded; furthermore, their skill practice becomes erratic and unpredictable (Kantak & Winstein, 2012). Cognitive load theory is a little-known term in ultrasound educational literature.

Cognitive load theory suggests that a learner's working memory has a finite and limited capacity (van Merrienboer & Sweller, 2010; Kantak & Winstein, 2012). Therefore, it is important for educators to manage the cognitive load placed on a learner's working memory when they teach a psychomotor scanning skill. Managing the cognitive load requires the educator to be cognisant of the impost of: (1) the type, quantity, and complexity of skill they are teaching (intrinsic load), (2) what pedagogical approaches are used to teach the psychomotor skill (extraneous load) during the initial and mid stages of learning a psychomotor skill, and (3) the effort that is associated with learning that is distinct from performing the task (germane load) as the learner's skill practice becomes more advanced (Young et al., 2014). This research project is the first to highlight the importance and relevance of cognitive load theory to the pedagogical approaches that educators use when teaching ultrasound scanning skills.

High intrinsic load is experienced when a multi-part and new scanning skill is taught in one skill-teaching session. This study's results showed that approximately 55% of the educators taught a scanning skill in one teaching session. This teaching practice should not be used for most ultrasound scanning skills because the volume of knowledge taught in the one skill-teaching session is too much. Therefore, it is important for the educator to perform task analysis to identify the number of skill sub-parts that are involved in its execution (see Chapter 4 for a review). It is also essential that when each skill sub-part is taught that it contains no more than seven skill steps (Young et al., 2014). In circumstances where a skill sub-part contains more than seven skill steps it would be divided into two chunks and each chunk would be taught and then linked together (van Merriënboer et al., 2006). A large majority of the respondents reported that they perform task analysis. This study also found that a large majority of the respondents undertook a reconnaissance of the learner's prior skill knowledge before they taught the skill. The benefit of first undertaking task analysis followed by establishing the learner's skill practice knowledge is that the educator can avoid reteaching theoretical and procedural knowledge that is already known.

Likewise, when the level of prior skill knowledge is known this information can be used to moderate the quantity of information that is taught in a teaching session, therefore limiting a learner's intrinsic load. However, this study did not explore whether educators used this knowledge to then moderate the amount of information that was taught to the learner.

Many of the pedagogical approaches that the educator chooses to teach a psychomotor skill will influence the learner's level of extraneous load (Young et al., 2014). For example, approximately two thirds of respondents broke a task down into sub-parts, then progressively taught each sub-part, and then followed by linking the sub-parts until whole-task practise was ultimately achieved. The frequency of these reported teaching practices provides new knowledge about the pedagogical steps being used by sonographers to teach psychomotor scanning skills and also to manage a learner's cognitive load. However, the reasons why the participants used these teaching practices was not explored in this research.

The results of this study found that a statistically significant proportion of the responders used short practice sessions and this practice approach also reduces a learner's extraneous load. Using short, spaced, and multiple practice sessions of less than 60 minutes facilitated the encryption of the motor map for the skill (DeBourgh, 2011; Kantak & Winstein, 2012; Young et al., 2014). Ericsson (1993) points out that skills are only acquired through their diligent practice. Importantly, Kleim et al (2004) and DeBourgh (2011) assert that the frequency and repetition with which a task is practised impacts on the encryption of motor maps. Foy and Evans (2009) also support the need for multiple short practice opportunities when encrypting the motor map for a skill. DeBourgh (2011) and Kantak and Winstein (2012) argue that long and infrequent practice sessions may deleteriously affect skill encryption and cause learner fatigue. Numerous practice sessions (less than 60 minutes in duration) and variable task sequence practice opportunities facilitate the process of skill encoding, consolidation and recall (Poole, 1991; DeBourgh, 2011; Kantak & Winstein, 2012; Spruit et al., 2014). Therefore, the use of short practice sessions is beneficial for the development and encryption of a motor map and to manage a learner's intrinsic and extraneous cognitive load.

In contrast, the results of this study found that longer practice sessions, of greater than 60 minutes, are sometimes opportunistically seized by the educators when patients consent to the learner scanning them. This is a compensatory practice used by educators to try and replace the learner's lost practice opportunities. There are many levers which serve to influence the skill-

teaching and practice opportunities provided to learners in authentic clinical practice and they include: (1) the competing interests of trying to manage and maintain a satisfactory workflow when working in a busy department and also trying to provide practice opportunities to the learner, (2) the well-being of the patient limited skill practice opportunities, (3) the willingness of the patient to consent to a learner practising their scanning skills on them (and as a result the learner may have irregular and inconsistent practice opportunities), (4) the duty of care to the patient and performing a gate-keeper role that the educator has to prioritize the patient ahead of the learning needs and goals of the student, and (5) the limited theoretical knowledge of sonographers about the pedagogical approaches required to teach psychomotor skills, and the assumption that there is little benefit from the learner practising the skill for a short period of time. These factors, in concert, generate unpredictable teaching and learning opportunities, and there is a lack of knowledge and fiscal data about the true impact about the training outcomes in these teaching environments.

An educator can manage a learner's cognitive load through a number of means. First, adopt pedagogical approaches that are intended to limit the amount of new and complex information taught in any one teaching session. Second, limit the number of concurrent tasks performed at the one time. Third, use a pedagogical approach that simplifies the type and quantity of information taught and practised at any one time. A learner may experience information overload when these factors are encountered in isolation or in concert. Although, in the context of acquiring and learning complex psychomotor scanning skills, it is unclear which of these three factors has the greatest impost upon a learner's working memory and causes the greatest degradation of working memory capacity. Further research is required to determine the influence and the relationship of these three factors when teaching and learning psychomotor scanning skills.

12.5.1.4 *End-task feedback*

The primary goal of feedback is to progress the learner's skill performance. Notwithstanding skill rehearsal and repetition, feedback is the single most influential teaching practice to promote motor learning (Ende, 1983; Molloy, 2009). A large majority of respondents (83%) reported that they provided end-task feedback to the learner. However, the feedback was mostly unidirectional, from the educator to the learner, e.g. sonographers giving a monologue about student practice performance. It is important that there is a two-way exchange of information between the educator and the learner when feedback is given about the practice performance. This is because, the exchange provides the learner with the opportunity to consider and reflect upon the practice

performance. More than half of the respondents did not provide an overview of the skill practice to the learner or ask the learner to reflect on their practice performance nor identify what they did well. These steps are important to advance a learner's practice performance and for the development of a learner's reflective practice. Therefore, it is suggested that further education is required to equip those sonographers, who are involved in formal or informal teaching roles, with the theory and practice knowledge of the role and application of end-task feedback when teaching scanning skills.

12.5.2 Heuristic pedagogical approaches

The results of this study have also shown that a large majority of respondents used coaching and guidance, physical guidance, and immediate error-correcting feedback (or in-task feedback) to support a learner's acquisition of a scanning skill. These results present new knowledge about the use of these instructional approaches when teaching and learning a scanning psychomotor skill. A large majority of respondents (92%) reported that they provided coaching and guidance while a learner initially practised acquiring scanning skills. There is limited health professional educational research about the use and application of coaching and guidance and physical guidance when first teaching a complex psychomotor skill; although, there is a plethora of research which suggests that when a skill is simple, these pedagogical approaches should be restricted or not used to avoid the learner becoming reliant upon feedback (Wulf & Shea, 2002; van Merrienboer & Sweller, 2010).

During the initial skill acquisition and encoding stages, when the skill is new and complex, the learner does not have the ability to detect and correct skill execution errors. This is because, they have not yet developed a mental schema or motor map for the skill. Consequently, the goal of the educator providing in-task feedback is to ensure that the skill is practiced correctly and that all skill practice errors are immediately corrected. As the skill continues to be practiced, the feedback should be tapered. It is essential that in-task feedback is faded to ensure that the learner is given an opportunity to create an error free mental schema for the skill. Then, the learner has the capability to be able to identify and correct their skill practice errors. The results of this study found that a large proportion (79%) of the respondents provided error-correcting feedback and asked the learner to re-perform the skill part correctly.

Physical guidance is one pedagogical approach that can be used to communicate to the learner the skill movements that are needed to achieve the movement goal or to provide error correction

feedback (Wulf & Shea, 2002; Dresang et al., 2004; van Merriënboer et al., 2006). It involves the educator placing their hand over the learner's hand and then guiding their scanning movements to achieve an optimal outcome for the each clinical practice scenario (Dresang et al., 2004; O'Connell et al., 2006). Approximately two thirds of the respondents (65%) reported that they provided physical guidance while they taught and guided a learner's skill execution. In medical ultrasound education there is very little research which has examined the effectiveness of providing such physical guidance.

Providing physical guidance, and guidance and coaching are forms of in-task feedback. Therefore, when complex skills are being taught and learned these instructional approaches should be restricted to a finite period and used only in the very early stages of the skill acquisition process and then tapered (Sigrist et al., 2013). This practice will avoid the degradation of the long-term learning and recall of the skill (Salmoni et al., 1984; Walsh et al., 2009). Therefore, further profession-specific research is required to establish the long-term learning outcomes from the provision of the in-task feedback when first acquiring psychomotor scanning skills.

12.5.3 Teach the whole scanning skill in a single session

Approximately 55% of the respondents reported that they may teach the whole scanning skill in one teaching session. This practice was reiterated in open-text responses, and they were most likely to teach the whole scanning skill in one teaching session when they taught a qualified sonographer, or they had determined that a simple skill was involved. This research has identified that many sonographers self-evaluate and self-determine the complexity of the ultrasound scanning skill that they are intending to teach. However, the respondents did not identify that they used an evidence-based approach to classify scanning skills.

12.5.4 Preparation for and providing educational support

The results of the study show that most sonographers (83%) who work with others perform an informal skill-teaching or support role. Most responders pointed out that they helped their colleague obtain an image of a structure, provided guidance and direction about how to interpret a finding, or measure a structure. This research finding makes an original contribution to the knowledge about the implicit practice role that a sonographer executes when they work with others.

The teaching and learning skill development of the participants varied. Participants reported that their clinical skill education ranged from none, to conference workshops and short courses, to

informal training, and tertiary qualifications. Approximately a third (32%) of the respondents had completed a college or university clinical health education certificate or degree. From this higher educated cohort, only one third of the respondents identified that they used a skill-teaching model to guide their clinical teaching practices. Those sonographers who had completed a graduate diploma or a masters in coursework reported that they were most likely to use a skill-teaching model to teach psychomotor scanning skills. Whereas, 76% of the cohort reported that they had not completed informal clinical health educational training courses, such as undertaking a train-the-trainer course. A further finding of this research is that the majority of respondents reported that their main source of sonographer clinical education was through attending workshops and courses provided by ASA and ASUM. The respondents reported that they had either attended professionally-administered day or weekend workshops, lectures, or courses.

12.5.5 Simulation to teach scanning skills

This study has shown that most scanning skills are taught either in authentic clinical practice or on staff members. A large majority of respondents (83%) reported that they did not use simulative aides or simulation to teach the initial scanning skills required for clinical practice, which means 17% did. Compared to the 45 % of the cohort who reported that they practised on staff members or colleagues (e.g. a simulation), this suggests that many of the respondents may not be aware that using people as scanning models is a type of simulation. These findings make an original contribution to knowledge as this research is the first to quantify the prevalence of this pedagogical approach to teach scanning skills. Having this understanding is the catalyst to explore, in future research, why simulation is not used more widely as a pedagogical approach to teach the initial scanning skills required to perform an ultrasound or to target an area of clinical practise which requires intentional and repeated skill practice to gain skill proficiency.

Respondents identified that it was beneficial to teach the initial scanning skills on simulative aides and not on a "real" patient. This is because the sonographer educator does not have to focus on the execution of three roles while teaching scanning skills on the job. These three roles are delivering patient centred care, being a gatekeeper of information to the learner in front of the patient and providing sufficient teaching and learning opportunities and feedback to assist the progressive skill advancement of the learner. Open-text responses in this research identified that the use of simulation to teach scanning skills enabled the educator to move the teaching environment from being patient- to learner-centred. Many respondents reported that the main advantage of using simulation to teach scanning skills was that they did not need to censor their

communication with the learner. Additionally, scanning skills could be isolated and then repeatedly practised on manikins without causing harm or alarm to the patient.

12.6   Far-reaching Implications of this Research

This body of novel publications and research has extended the profession-specific knowledge about the psychomotor scanning skills that are used to perform an ultrasound. This thesis has outlined the motor-learning domain theoretical principles to teach a complex psychomotor skill. The research has revealed the pedagogical approaches used by Australian sonographers to teach scanning skills. The research has been ground-breaking on many fronts. For example, it is the first in the ultrasound literature to chronicle how to develop and validate a survey instrument to measure sonographer skill teaching perceptions. The publication of the iterative steps required to develop and validate the instrument makes an original contribution to knowledge. Furthermore, this thesis has provided an overview of which methodological steps should be taken or avoided when progressively developing a survey instrument. This honest account should provide the support and guidance for other researchers who wish to continue in this vein of enquiry, so that they can produce well-developed surveys without also making the same mistakes.

The results of this research have provided world-first data on the pedagogical approaches used to teach scanning skills. An important outcome of this research was establishing that Australian sonographers use the two-step skill teaching model to teach psychomotor scanning skills. This is the first published research to point out that this instructional approach is being used by the profession. A few pioneers of the profession first taught themselves how to use the ultrasound scanning equipment and then they taught others. The master-apprentice or two-step skill teaching model has continued to be used even though the scanning skillset (to use and operate the equipment) became progressively more sophisticated and complex. The results of the research suggest that many sonographers teach scanning skills how they were taught by the pioneers of the profession. This original contribution to knowledge has enabled a critical review of the two-step model to teach psychomotor scanning skills. The review has identified that there are four main factors why the ultrasound profession should not be using this model to teach complex psychomotor skills. These four factors have been forensically reviewed and described in the thesis. There is a corpus of motor-learning research and knowledge which outlines that educators should use evidence-based instructional approaches when they teach a complex skill. Therefore, it is important that sonographers are educated about these motor-learning theories and principles to

teach a psychomotor skill. The lack of profession-specific research by the sonography profession has fostered an acceptance of the status quo. There is now a pressing need for the sonography profession in Australia to rethink how it currently teaches scanning skills. It is essential that the profession undertakes further research to review the skill-teaching and learning outcomes derived from using these suggested teaching approaches. This is because this thesis has not explored which skill-teaching approaches are best suited to the complexity of the psychomotor skills used to perform an ultrasound scan.

Ultrasound imaging is used by a disparate group of health professional operators across the globe. There has been limited literature about the pedagogical approaches that these operators use to teach ultrasound scanning skills. Although, there is some anecdotal evidence to suggest that these professions use ad-hoc teaching approaches or the two-step skill teaching model to teach ultrasound scanning skills. Therefore, the outcomes of this research has relevance to those health professionals who teach scanning skills in their discipline across the world. The motor learning theories, principles, and neural processes that accompany the teaching and learning of a complex psychomotor skill are applicable to all health professionals who teach and learn psychomotor scanning skills. Therefore, the results of this research have far ranging application and relevance.

12.7 **Recommendations**

This research provides a corpus of new knowledge about the current pedagogical approaches that are being used to teach psychomotor scanning skills and has identified the knowledge that is required to support a formal and informal skill-teaching role.

Recommendations from this thesis include:

1. Increase the awareness within the profession that many sonographers perform formal and informal teaching roles and there is a need for specialised education to support them in their skill-teaching role.
2. To conduct targeted education to teach the core motor-learning theory and principles to all sonographer educators employed in dedicated clinical teaching and supervision roles. A particular focus should be placed upon the pedagogical steps to teach a complex psychomotor skill and the role and purpose of in-task and end-task feedback.
3. To advocate that sonographers need protected teaching time to ensure that psychomotor skills can be taught using evidence-based skill-teaching approaches.

4. To suggest that the professional ultrasound bodies in Australia provide governance policies and consent forms for the use of workplace peers or staff members as scanning models. Furthermore, policies and procedures are required for when adverse scan findings are encountered when staff members are being used as 'dummy' patients.

5. That professional ultrasound bodies in Australia provide governance policy and procedures for the use of touching their fellow peers when performing physical guidance.

12.8 **Future Research**

This research has provided an original contribution to knowledge by describing the pedagogical approaches that are being used by Australian sonographers to teach scanning skills. The results of this research provide new knowledge about how scanning skills are currently taught. This knowledge was antecedent to being able to critically review the skill teaching practices used by Australian sonographers to teach scanning skills. Undertaking this research and analysis were the first steps to understanding which skill-teaching practices are being used. Considerable research is still required to determine what are the optimal pedagogical approaches are to use to teach and learn psychomotor scanning skills and why. The following recommendations for future research stem from this thesis:

1. To undertake a review of the categorization of the psychomotor scanning skills used to perform an ultrasound.

2. To determine what is the optimal skill-teaching approach to use to teach psychomotor scanning skills.

3. To determine whether the 11-step or a 12-step skill teaching model is best suited to teaching complex psychomotor scanning skills. The 12-step model would involve the educator providing two silent skill demonstrations of each of the upper limb scanning movements. The first skill demonstration provides vision of the motor movements used to move the transducer of perform image instrumentation or optimisation. The repeated and second silent skill demonstration provides the learner with the visual outcome of the movements on the ultrasound monitor.

4. To establish whether learners can discern and perceive the small motor movements that are performed by the fingers (to guide the movement of the transducer) during ultrasound skill demonstration.

5. To explore the role and application of providing guidance and coaching and the provision of physical guidance during the initial stages of acquiring a complex psychomotor skill

6. To understand at what time point in-task feedback should be faded, by the educator, when they first teach a psychomotor scanning skill

7. To identify whether there are deleterious effects on the long-term acquisition and retention of psychomotor scanning skills when in-task feedback is provided during the initial stages of skill acquisition

8. Explore perceived or real barriers to sonographers using simulation to teach scanning skills.

9. To establish whether the use of low-fidelity phantoms cause the creation of an incomplete mental schema.

10. To further research and understand the optimal pedagogical approaches that are needed to acquire, integrate, and perform dual upper limb motor tasks used to complete an ultrasound examination.

12.9   Concluding Statement

This research has outlined that performing a scanning skill is a complex psychomotor skill. Psychomotor scanning skills are an integral part of performing an ultrasound examination. The results of this inaugural research have shed light on the pedagogical approaches currently being used to teach scanning skills. The findings identified that most Australian sonographers use a two-step model to teach psychomotor scanning skills. Other pedagogical approaches used to teach a psychomotor scanning skill include: undertaking task analysis, establishing the learner's prior skill knowledge, providing guidance and coaching, using physical guidance, correcting all skill errors immediately when they occur, and providing end-task feedback.

This thesis has outlined that there are several skill-learning limitations from the pedagogical approaches that are currently being used by sonographers in Australia when they teach psychomotor scanning skills. Therefore, there is a pressing need to identify what are the optimal

pedagogical approaches to use to teach complex psychomotor scanning skills. This future research is important to ensure that the scanning skills are taught efficiently and that the pedagogical approaches used to teach scanning skills foster the learner's long-term retention of the skill. There is also an accompanying need for those sonographers involved in teaching scanning skills to have the knowledge of the motor-learning theories and principles related to teaching a complex psychomotor skill. These two outcomes are relevant and important for all users of ultrasound imaging in Australia and across the globe.

APPENDICES

Appendix 1: Literature review - the characteristics of the retrieved studies

Author, year, study location, publication type	Participants and number (*n*=)	Professional cohort	Aim of the study/report	Methodology	Skill teaching approach	Outcome measures	Important results
Dresang et al. (2004)\n\nUSA\n\nPeer reviewed. article	Nil.\n\nReview article.	Family medicine residents.	To outline the curriculum and instructional approaches required to teach family medicine, residents, prenatal ultrasound, and gynaecological ultrasound.	Nil.	Didactic lecture followed by supervised scanning practice.	Nil.	Authors point out that learning to scan is just one domain of knowledge required by the learner to perform an ultrasound.\n\nLearners require knowledge of ultrasound physics, machine usage, indications for the ultrasound examination, how to perform an anatomical survey scan, and how to perform fetal biometry across the trimesters of pregnancy.\n\nLearners profit from supervised scanning practice until skill competency is attained.\n\nHowever, authors point out that the details of ".... the best method of teaching prenatal ultrasound is sparse...." (p. 106).
Sonaggera (2004)\n\nUSA\n\nPeer-reviewed article	41 general student sonographers.	Sonography – beginning and advanced.	To explore student skill teaching and clinical education perceptions.	Survey.	NA	NA	Different instructional approaches are required for beginner and advanced students.\n\nHighlighted many of the subcomponents of the scanning skills needed to perform an ultrasound examination.\n\nBeginning students wanted to observe in authentic clinical practice and observe where to place the transducer; how to move and manipulate the

							transducer; and how to position the patient. Next, they wanted to try and replicate the observed skills and compare their image/ measurement with the educator's image. Beginning students point out that they found it a challenge to perform scanning and image instrumentation and optimisation.
Arger et al. (2005) USA Peer reviewed article	33 Medical students.	Novice. Undergraduate medical school students.	To determine whether using didactic lecture and skilled supervised ultrasound training improved scanning skills	Pre and post-test- MCQ and assessment of post training images. Four 2-hour teaching sessions. Students scanned each other. No control group.	Demonstration and supervised skill practice. Skilled educators, sonographer, and physician were used to teach and guide the acquisition of the scanning skills.	Pre and post MCQ scores and scoring of participants' acquired ultrasound images (aorta and kidney).	Significant improvement of post test scores for imaging the kidney and aorta after lectures/ pre-reading and skill demonstration.
Australasian Sonographers Association (2011) Australia Grey Literature * not made available on-line until 2014*	Nil. Competency framework document.	New graduate or entry level sonographers.	To outline the minimum standards of knowledge and clinical practice required by an entry level sonographer.	Not described.	Not described.	NA	NA
Brown et al. (2011) Guest editorial	4 cardiac student sonographers. 8 cardiac clinical supervisors.	Cardiac sonography.	To explore student skill-teaching and clinical education practices and perceptions by students and	Two evaluation forms were completed by both cohorts' pre and post clinical	Ad hoc and opportunistic.	Evaluation of student and supervisors' perceptions.	Scanning skills are often taught using an ad hoc approach due to limited training time and clinical teaching knowledge by the cardiac sonographers who are also

			sonographer educators.	supervision. Further evidence was garnered through informal discussion with the cardiac supervisors.			performing a clinical supervision/education role.
(Moore & Copel, 2011) USA Peer-reviewed article	Nil. Review article.	Point-of-care (POC) ultrasound.	To report the history, teaching approaches, and clinical applications related to POC ultrasound.	Nil.	Didactic tutorial and expert narrated video demonstration. Four teaching videos were included which provided expert skill demonstration with a verbal overlay of key information.	NA	Author points out the scanning planes used to perform an ultrasound include sagittal, transverse, coronal, and oblique. Probe orientation conventions are described. For general scanning the notch/bump/groove on the probe is moved right or cephalad according to the plane of imaging and corresponds to the left side of the screen. Cardiology uses the reverse convention. TV ultrasound was not discussed. FAST ultrasound examination refers to focused assessment with sonography for trauma- main goal to detect fluid in the abdomen/pelvis. e-FAST ultrasound refers to an extended examination which includes the chest for pneumothorax. The e-FAST exam aims to detect fluid in the abdomen, pelvis, pericardium, and lungs, and to exclude a pneumothorax. A complete or partial FAST ultrasound may be performed on those patients who do not present with trauma but other pathologies.
Thoirs and Coffee (2012) Australia	5 sonographers. Advanced students or recently	Musculo-skeletal (MSK) Sonography.	To assess the ability of a multi-media tool to develop scanning skills to	Pilot study. DVD used to facilitate the self-directed	DVD learning tool included audio-visual recording of sonographic technique and	Pre and post intervention testing using a	Competency was achieved by all learners performing simple tasks. Most of the cohort were unable to perform more difficult and advanced

| Peer-reviewed article | graduated participants. | | perform ankle and foot MSK imaging. | learning of MSK skills.

Self-report on learning experience.

Baseline testing followed by 3-month follow up.

Colleagues used as scanning models.

No control group. | protocol images for ultrasound assessment of 18 ankle and foot tendons. | developed rubric. | anatomical examinations in the time frame.

There was no demographic data provided for the cohort. This omission has impeded the analysis of the data because it was not possible to explore whether participants who were able to image some of the more difficult tendons did so because they were credentialed and therefore had more prior knowledge and scanning skills or students, or because of other factors.

Authors suggest another teaching approach may be warranted when teaching challenging and complex tasks. However, they do not explore the motor-learning theory and principles related to teaching a complex psychomotor skill. |
| Sultan et al. (2013)

Ireland

Peer-reviewed article | Nil.

Review of simulators for ultrasound guided procedures. | Anaesthesia and intensive care medicine. | To report upon the use of simulators to develop the four main categories of skill required to become a proficient operator of ultrasound guided regional anaesthesia. | NA | NA | Extant review of simulation aides to assist with the development of scanning skills. | Authors highlight that "Traditionally, procedural skills have been acquired through an apprenticeship model" (p.130).

Skills are demonstrated by an expert; the learner observes and then practices the skill under supervised practice conditions (p.130).

The opportunity for teaching and learning psychomotor skills is contracting in the clinical space.

Skill acquisition is reliant upon deliberate practice and the receipt of feedback.

Simulation provides one option to first acquire the scanning skills and then |

							transfer them to the clinical practice environment. Deliberate practice requires repeated practice and the receipt of objective, targeted, and detailed feedback.
Cartier et al. (2014) USA Peer-reviewed article	Emergency medicine residents/physician. 38 pre-course and 34 post-course participants.	Point-of –Care ultrasound (POCUS).	To identify those methods that provide the best educational value as determined by the learner.	Qualitative approach using pre-course and post course surveys.	Didactic lecture. Master apprentice skill-teaching model. Skill demonstration followed by supervised clinical practice. All students were rotated through large group skill demonstration and small group hands –on practice scanning sessions.	Quantitative and content analysis of survey data	The respondents identified that small group teaching (3-5 students, 60-120 mins) was preferable to large group teaching (15-18 students 30-60 mins) to learn scanning skills. Students perceptions identified that: (1) hands on scanning was preferred to view the educator perform the larger group skill demonstration, and (2) that respondents pointed out that attending the didactic presentation was the least preferred educational activity. Students preferred short video clips of anatomy or pathology examples compared to still images in the PowerPoint lectures provided.
Gibbs (2014) UK Peer-reviewed article	12 Student sonographers.	Sonography.	To determine whether simulation can enhance the learning of scanning skills.	Qualitative approach. Semi-structured interview.	A skill-teaching approach was not described.	Thematic analysis of verbatim transcripts.	Participants identified that they had the opportunity to practice and perform transducer manipulation and orientation without having to concentrate on other machine functions or talk to the patient.
Montealegre-Gallegos et al. (2014) USA Peer-reviewed article	Transoesophageal echocardiography (TEE).	Cardiology.	Editorial of the use of simulation to teach TEE.	NA	NA	Simulators equipped with self-learning tutorials provide a structured and standardised method to teach the core psychomotor skills using skill demonstration	Simulation provides the opportunity to isolate and practice a skill repeatedly until competence performance is achieved. Simulators equipped with self-learning tutorials provide a structured and standardised method to teach the core psychomotor skills using skill demonstration and providing an exemplar of performance.

							and providing an exemplar of performance.	
Nicholls et al. (2014) Australia Peer-reviewed article	Theoretical paper.	Sonography.	To report and document the skill set required by operators who perform ultrasound examinations.	NA	NA	NA		Authors defined a psychomotor skill. Identified ultrasound imaging used - mainly open skills. Therefore, the series and combination of skills to move and manipulate the transducer are often unique to each patient. Defined visuo-motor and visuo-spatial skills as they relate to performing an ultrasound examination.
Webb et al. (2014) USA Peer-reviewed article	Pre-clinical medical students (*n*=106)	First year medical students	Pilot program to teach ultrasound scanning skills	Survey responses pre and post teaching intervention	Small group hands-on scanning practice			Points out that operators need to know the role and limitations of ultrasound imaging; expertise take years to acquire and needs ongoing hand on clinical practice and feedback
Australasian Sonographers Association (2015) Australia Grey Literature	Nil. Clinical supervision report.	Sonography.	To outline the theory and pedagogy related to a sonographer undertaking a clinical supervision or education role.	Not described.	Provides a four-step model proposed by Peyton to teach scanning skills. The four steps include demonstration-the skill is demonstrated by the educator at normal speed; deconstruction-the educator repeats the demonstration slowly and describes the main skill steps to perform the task; comprehension-	There is no outcome data to support the endorsement of this skill-teaching model to teach the scanning skills required for clinical practice.		NA

					the educator performs the skill after the learner describes the steps to perform the skill; and performance-the learner performs the tasks and they provide a narration of the skill steps (p.19).		
Crofts (2015) UK Peer-reviewed article	4 student sonographers were observed over a 12-month period.	Sonography.	To develop a framework to guide the learning in ultrasound scanning.	Direct observation and semi-structured interviews. Purposive sampling.	Demonstration, skill practice, and feedback.	Narrative and thematic analysis of the practice observations and the interview transcripts.	Points out that little attention has been paid to the pedagogical approaches that are used to learn the scanning skills required for clinical practice. Paper reports on three main points related to teaching a psychomotor skill: 1. observation of expert practice helps with knowing what the scan should look like, how to move and manipulate the transducer, how scanning techniques need to adapt in certain clinical scenarios and to develop confidence in your own scanning abilities; 2. feedback on performance provided by the same educator during and after the scan; and 3. skill practice commences on static structures and then progresses to easy and normal patients and then to progressively more challenging practice encounters.
Gibbs (2015) UK Peer-reviewed article	25 Student sonographers.	Sonography.	To further explore the role of simulation to develop the skills required to perform an ultrasound examination.	Qualitative approach. Semi-structured interview.	A skill-teaching approach was not described.	Thematic analysis of verbatim transcripts.	Simulation provided the opportunity to understand transducer orientation, the scan planes used to assess organs, the visual impact of moving the transducer and how this changed the ultrasound image – referred to as visuo-motor skills, and the 3D spatial relationships of

| | | | | | | | 2D anatomy – referred to as visuo-spatial skills.

Performing an ultrasound examination involves many complex skills such as patient interaction, clinical decision making, and writing an ultrasound report of the scan findings. |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Lavender et al. (2016)

Australia

Peer-reviewed article | Sonographers. | Sonography. | To determine whether the fetal corpus callosum can be demonstrated using 2D ultrasound imaging after intensive training. | Retrospective cohort study pre and post intensive training of 300 images acquired from second trimester scans. | Didactic presentation and one-on-one clinical skills training session with a sonographer educator.

Technical advice was given about the acoustic windows, transducer movements, and assessing and interpreting the images. | Prior to intensive training the corpus callosum was visualised 23% (35/150) of fetuses and after training the structure was detected in (107/150) 71% of cases. After intensive training the CC could only be seen in 71% of fetuses. However, data was not collected about those fetuses where the CC could not be seen due to poor fetal position. Non-visualisation dropped from 29% to 6%. The mean time for visualisation was 56.2 seconds and 94% of exams | Imaging the corpus callosum with 2D ultrasound is a difficult psychomotor skill.

Teaching approaches need to consider the complexity of the psychomotor skills the student is learning.

Fetal position affected the visualisation of the corpus callosum.

Not all sonographers received the same teaching and training – in particular, part-time employees. |

							took less than 90 seconds.	
Thoirs et al. (2016) Australia Peer-reviewed article	18 student sonographers.	Sonography.	To evaluate whether scanning skills could be taught using simulation.	Four skill development activities using simulated workstations were used to teach basic scanning skills and assess transfer to the clinical practice environment.	Didactic lectures, real-time and DVD skill demonstration, and supervised practice.	Post skill outcome evaluation measured on a Likert scale questionnaire. Outcomes are not identified using the measurement tool.	No strong evidence that high fidelity ultrasound simulated learning improves skill acquisition compared to current on-the job clinical training. A scaffolded skill curriculum may improve skill learning outcomes. No skill retention or transfer data recorded.
Greenstein et al. (2017) USA Peer-reviewed article	Critical care N=363.	Critical care physicians, surgeons, advanced practice nurses, and medical residents.	To report on the effectiveness of a critical care ultrasonography course.	Participants who attended five consecutive 3-day critical care ultrasonography courses completed pre and post test scores. Hands on test scores.	Didactic lecture and hands-on-training using human models. 1:3 faculty to student ratio for clinical practice. Supervised review of 30-40 video library clips of normal and abnormal findings.	Pre and post test scores. Hands on test scores for the domain of image acquisition. Standardised exam format comprised of 20 clinical skills are scored being executed on human models.	Only one brand of ultrasound machine was used to teach the scanning skills at these courses. Variation in human models provides a range of practice encounters. Participant baseline knowledge and skills are assessed prior to starting the course using a 20-minute video-based examination. The average pre and post test scores were 57% and 90% respectively. The post-test average hands-on score was 86%. These statistics suggest that for the knowledge and psychomotor skills taught and assessed this course was successful in teaching a core skill set. No data on skill retention or transfer.
Meadley et al. (2017) Australia Peer-reviewed article	Scoping review. Training Paramedics in ultrasound.	Paramedics.	To explore the educational approaches used to teach paramedics ultrasound in the	Scoping review of peer reviewed and grey literature from 1990-2016.	Didactic lecture and practical teaching "hands-on session". Teaching approach did not change when teaching	The methodology used across the studies varied widely.	9/20 studies included 10 or less participants. The others included participants numbers ranging from 15-90. The range of clinical conditions that ultrasound was used for was diverse

					Focused Assessment Sonography for Trauma or cardiac scan. Duration 2 minutes to 2 months. Scanned real patients (with and without ascites), standardised patients, cadaver models, simulation models, and turkey leg bone, and swine animal models.	Prospective observational pilot study, prospective educational intervention study, blinded randomised controlled trial, single blinded RCT, prospective multicentre study.	and included cardiac, lung, peripheral venous access, long bone fractures, Focused Assessment Sonography for Trauma, location of endotracheal tube placement, and one study not reported. The review studies included a broad range of assessable tasks to evaluate learning outcomes related to performing a diverse range of POCUS examinations. For example, ability to acquire images to a given standard, ability to identify and describe pathology from images/clips, and operators' ability to detect pathology using ultrasound. Only one study provided sensitivity and specificity. Post course data - questionnaire score versus score from same test 12/12 later. The variable curriculum course duration made it difficult to extract meaningful results.
out-of-hospital setting.							
Pessin and Tang-Simmons (2017) USA Peer-reviewed article	21 student sonographers.	Sonography. Testicular scanning.	To describe the student perceptions of simulation to teach the machine, patient, and scanning skills. Pilot project.	Anonymous survey. Convenience sample.	Didactic lecture followed by scanning session and supervised practice.	Content analysis of survey responses.	Students valued the opportunity to practice in a low risk scanning environment and receive immediate feedback on their practice performance. The novice sonographers in their first year of clinical practice have observed 10 or fewer scrotal examination and therefore their confidence in performing the task was low.
Ryan (2017) Australia	Nil. Narrative report.	Sonography.	To chronicle the evolution of clinical supervision and changing	Nil.	One-to-one training and mentoring.	NA	Paper critically identifies the scanning skills and their sub tasks, that are needed to perform an ultrasound examination.

Peer-reviewed article			educational requirements.		No specific teaching approach described.		Paper explicitly points out that performing an ultrasound examination is comprised of many subcomponents; the scanning skills are just one domain of clinical practice required to become a safe and reliable operator.
Ahmed et al. (2018) Ireland Peer-reviewed article	Medical students *N*=18.	Anaesthesiology.	To compare the impact of novice skill acquisition using deliberate and self-guided skill practice to perform the task of advancing a needle to a target location within a gel imaging phantom.	Two student cohorts. One group assigned to self-guided practice (n=8); the other to supervised deliberate practice (n=10). Video assessment of skill performance by two qualified anaesthesiologists.	Didactic lecture and expert demonstration followed by self-directed practice or supervised practice. Practice time up to one hour.	Pre and post training scores (number of steps completed, and the number of errors made). Assessment immediately after and then 24 hours following the practice session.	Both groups showed improved skill acquisition compared to the baseline skills. Supervised deliberate practice resulted in novices' demonstrating more consistent performance, making fewer errors and completing more task steps. The provision of objective feedback to the trainee requires the development of a rubric which correctly describes the skill steps and the expected standards of performance. The student should be made aware of the expected standards of performance practice.
Davis et al. (2018) USA Peer-reviewed article	NA 95 articles included in the review.	Teaching ultrasound to medical students.	To conduct a systematic review of the educational outcomes related to teaching ultrasound to medical students.	Systematic review of peer-reviewed and grey literature performed in 2016. No date restriction. Limits- English language.	NA	NA	The pedagogical approach used to teach ultrasound scanning skills to undergraduate medical students included didactic lecture (68%), demonstration (37%), and hands-on/practical scanning (79%) (p.2670). Scanning skills were taught using peer students (33%), healthy volunteers (19%), patients (19%), standardised patients (13%), simulation/phantoms (27%), cadavers (6%), and animal model (1%) (p2670). Training duration ranged from a session of one hour to extended training over a 4-year curriculum.

								Students were taught ultrasound scanning through using one-to-one teaching or more commonly in small groups of 2-6 students (71%).
Edwards et al 2018 Australia Peer-reviewed article	Review article.	Sonographers.	To review the concept of deliberate and its role in the initial development and then to refine scanning skills required for clinical practice.	NA	NA	NA		Performing an ultrasound examination is an example of a complex skill. Authors point out that skills are currently taught through observation, hand-on scanning, and the receipt of feedback. Ultrasound education providers have focused on the teaching of the knowledge related to being able to perform a clinical skill and far less attention on the pedagogical approaches used to acquire and learn the skill. Sonography requires the operator to perform several concurrent and complex skills. Movement of the transducer requires the operator to use variable combinations of transducer movements, angles, and pressure. For each examination the patient's anatomy and build will influence the skill set that is used to scan the patient. Deliberate practice involves targeted practice of a skill subcomponent and the receipt of real-time corrective feedback as the task is performed. Psychomotor skills are developed through regular practice and the provision of feedback.

							No feedback model was suggested by the authors to guide the information provided to the learner.
							The authors did not discuss important literature related to the timing, type, and quantity of feedback when learning a psychomotor skill.

Appendix 2: Survey panellists who reviewed the Pilot 1 and Pilot 2 SonoSTePs instrument

Panel member	Affiliation	Pilot 1	Pilot 2
A/Prof Linda Sweet,	Flinders University-Education	yes	yes
Prof Marilyn Baird	Monash University-Education	yes	no
Associate Professor Sue Campbell-Westerway	Charles Sturt University-Ultrasound	yes	yes
Name withheld	Sydney University-Statistics	yes	no
Dr Ann Quinton	Sydney University-Ultrasound	no	yes
Pawel Skuza	Flinders University-Statistics	no	yes

Appendix 3: Information sheet and national sonographer final survey

National SonoSTePs questionnaire

INFORMATION SHEET

Title: 'HOW AUSTRALIAN SONOGRAPHERS TEACH SCANNING SKILLS IN CLINICAL PRACTICE'

Investigators:
Delwyn Nicholls, Flinders University (Research Student)
Professor Linda Sweet, Flinders University (Supervisor)
Professor Jon Hyett, Royal Prince Alfred Hospital (Supervisor)
Pawel Skuza, Flinders University (Statistician)

The study

You are invited to voluntarily and anonymously participate in a national survey on Australian sonographer skill teaching practices labelled SonoSTePs. Queensland Sonographers were invited to participate in the pilot 3 testing of the SonoSTePs instrument. For statistical reasons, they will not be invited to participate in the national survey.

As you are aware medical ultrasound is a skills-based profession. The scanning skills required for practice, including scanning and documenting soft tissue structures and organs, are taught and learned through clinical instruction and the opportunity to practice the skill. However, there is no research to date about how we teach these scanning skills.

The study aims to explore how accredited sonographers teach sophisticated and complex scanning skills to both qualified and student sonographers in simulated or patient centred clinical practice learning environment and whether feedback on clinical performance is integrated into the skills teaching process. The survey asks sonographers to reflect on and document their skill teaching practices when teaching scanning skills and whether they provide feedback about skill performance. **The survey does not focus on the assessment of skill competence**. There is no right or wrong answer to questions on this survey.

The survey is estimated to take approximately 20 minutes to complete. This is an anonymous survey and all data is de-identified. Your responses to the survey questions cannot be identified. All results will be strictly confidential and only the investigators named above will have access to information and data provided by participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

While we intend that this research study furthers our knowledge about how sonographers teach scanning skills and provide feedback on skill performance in Australia, the results, may not be of direct benefit to you.

Participation in this study is entirely voluntary: you are not obliged to participate or commence the questionnaire and - if you do participate - you can withdraw at any time by not continuing or simply exiting the questionnaire.

When you have read this information and you wish to participate, begin the anonymous survey by double clicking on the hyperlink below, to the survey located on a site called SurveyMonkey. You will then be asked to press the Ctrl and left mouse key tabs to direct you to the survey. If you are not directed to the survey immediately, cut and paste the below url into your search engine address bar and press the enter key.

https://www.surveymonkey.com

Once you have finished the survey please click on the submit or done icon. Completion of this online survey is considered consent.

If you would like to know more information about this study, please feel free to contact Delwyn Nicholls at nich0309@flinders.edu.au or the student supervisor on the attached introductory letter. This information sheet is for you to keep.

Thank you for taking the time to read this information sheet and we hope that you will accept our invitation to be involved.

In Australia, how does the ultrasound profession teach psychomotor scanning skills required for clinical practice?

Thank you for participating in this online study at SurveyMonkey. Your participation in this survey is voluntary and all data cannot be identified or traced back to you.

Please make a note of **your start and finish time** and **record the completion time on the last page,** to complete the survey. However, as a guide, it is anticipated that the survey will take approximately 20 minutes.

You have been invited to participate in a national profession-based survey, which aims to garner a broad base of data and information about how sonographers teach   scanning skills in the clinical environment. There is little published data on this subject. The survey is exploring how sonographers (in their practices and in more formal teaching environments) teach scanning skills and provide information on skill practice. In particular the survey is aiming to;

a) Establish sonographer skill teaching practices

b) Explore whether sonographers in daily clinical practice identify with the implicit role of skills teacher and feedback provider.

c) Identify if sonographers utilise elements of published skills teaching and feedback models being utilised by other health professions, to teach clinical skills.

d) Establish whether simulation and simulated skill teaching activities are used to assist scanning skill development

Highlight- start your stopwatch NOW

Demographic and professional practice information

1. Please indicate you gender.

a) Male

b) Female

2. What is your age?

Please type your age in years………

3. Select the state or territory that you perform clinical ultrasound?

a) NSW

b) ACT

c) QLD

d) VIC

e) SA

f) WA

g) Tasmania

h) Northern Territory (NT)

i) Multiple states and NT (locum)

4. Select the location which you are employed at **the most clinical hours** per week as a sonographer?

a) Private practice

b) Public Hospital

c) Private Hospital

d) Equal private practice and public hospital practice

e) Nil- I am not employed in a clinical capacity

5. Which area of sonographic practice do you work the **majority** of your clinical hours? (Please select just one response)

a) General sonography

b) Cardiac sonography

c) Obstetric and Gynaecological sonography

d) Breast sonography

e) Vascular sonography

f) Paediatric sonography

g) Nil- I am not employed in a clinical capacity

h) Other (please specify)

6. Which of the following categories best describes your employment status?

a) Part-time (less than 35 hours per week)

b) Full-time

c) On long service leave

d) On maternity or parental leave

e) Locum part time

f) Other, please specify……

7. Which category best describes your **PRIMARY PLACE** of clinical practice?

a) I work as a solo sonographer at a single sonographer practice location

b) I work with two or more sonographers

c) I work as a locum sonographer in varying clinical practices

d) Other, please

specify………

……

8. What is the highest level of qualification in **ultrasound** you have completed?

   a) On the job training with grandfather credentialing

   b) TAFE certificate in ultrasound

   c) Diploma of Medical Ultrasound-Australian Society for Ultrasound in Medicine (DMU)

   d) Graduate Diploma

   e) Master in Ultrasound

   f) PhD

   g) Prefer not to answer

9. Which of the following categories best describes your **primary role** when employed in medical ultrasound?

   a) Clinical sonographer (primary role is to scan patients)

   b) Tutor sonographer

   c) Chief sonographer

   d) Clinical supervisor/assessor

   e) University lecturer

Sonographer skills teaching and feedback practice

Simulation based ultrasound skill education, is a teaching/learning context which utilises simulative aides to teach and foster scanning skill development. Examples of simulation learning aides include: plastic manikins, animal models, human cadavers and simulated or standardised patients (Dent and Harden, 2009)

   10. Do you teach scanning skills using simulated learning models? Please select one or more options below: -

   - Students

   - Colleagues

   - No please go to question 13

If yes please provide details of the type of simulative learning aides you employ to teach scanning skills……

……

………..

   11. Do you change your skill teaching approach when teaching scanning skills using simulative learning aides?

   - Yes

- Sometimes
- No

If Yes or sometimes, what aspects of your skill teaching approach do you change and briefly explain why?

....
....
....
....

12. When teaching scanning skills using simulated learning tools, do you teach these skills in a:

    a) Private practice

    b) Public hospital

    c) University teaching setting

    d) Private training/tutoring institution

    e) Other, please specify…………………………………………………………………………………………………
    ………

13. **Please select an answer for each question**. When teaching a sonographer an ultrasound scanning skill, do you?

	Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly Always (80-97%)	Always (98-100%)
A Teach a scanning skill using a published teaching model?							
B. Establish the learner's prior knowledge on the skill topic?							
C. Commence by silently demonstrating the skill?							
D. Repeat the demonstration with a description of skill steps?							
E. Repeat demonstration whilst the learner describes skill steps?							
F Learner describes skill steps as they demonstrate the skill?							
G. Correct skill performance errors immediately they occur?							
H. After correcting a skill error, ask the learner to re-perform the skill or task correctly?							
I. Provide guidance and coaching **during** skill performance?							
J. Provide skill practise opportunities in **long practice** sessions (more than 60 minutes)?							
K. Provide skill practice opportunities **in short practice** sessions (less than 60 minutes)?							
L. Provide a silent video of skill demonstration for teaching purposes?							

14. **Please select an answer for each question**. When teaching a scanning skill on a patient or imaging phantom, to a sonographer do you?

	Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly Always (80-97%)	Always (98-100%)
A. Change your teaching approach when teaching a student or accredited sonographer?							
B. Teach the whole skill at the first teaching session?							
C. Break a skill down into discrete or sub parts before teaching it?							
D. Teach a sub part of the total scanning skill?							
E. Progressively practice sub parts to whole skill practice?							
F. When teaching a new skill, assist learners scanning, by holding and guiding their scanning hand?							
G. When teaching a **novice**, you scan the patient first, followed by the learner?							
H. When supervising an **advanced student**, do they scan the patient before you do?	.						
I. When teaching a **qualified** sonographer a new skill, do you scan first, followed by them?							
J. Use staff members as scan models to teach scanning skills?							
K. Use phantoms to teach scanning skills?							

15. When teaching a clinical skill to a sonographer, do you provide verbal feedback (information) on their performance of the skill?

    a) Yes

    b) No- I work as a solo sonographer

    c) No - I do not know how to give feedback on skill performance

    d) No- I prefer not to be involved with giving feedback and guidance to my colleagues or students

16. **Please select an answer for each question**. In a skill teaching setting, when you OBSERVE a scanning skill performance, do you?

	Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly always (80-97%)	Always (98-100%)
A. Provide feedback during skill performance??							
B. Provide feedback at the **conclusion** of a skill performance?							
C. Limit feedback in presence of patient?							
D. A Deliver feedback using a model to guide delivery and content?							
E. Ask for an overview of skill performance or how they felt they went?							
F. Ask the learner what was done well and why?							
G. State what was done well and why?							
H. Ask the learner to identify what could be improved and how?							
I. Identify what aspects of skill performance could be improved and how?							
J. Provide a summary of skill performance and identify performance areas for learner to focus on?							
K. End feedback session with positive comment (s)							

Experiences as a learner and teacher

17. Have you completed extra training in health education, such as completing the "train the trainer" course or sonographer education/training workshops/courses conducted at national conference?

- Yes
- No

If yes please specify……

………

18. What is the highest level of qualification in **health education i.e. teaching/training qualifications,** you have completed?

a) None

b) Graduate certificate

c) Graduate Diploma

d) Master by coursework

e) PhD

f) Master by research

g) Prefer not to answer

19. Select which **teaching/training** roles you perform **in addition** to your primary clinical sonographer role?

a) No- I do not perform additional clinical teaching/training roles in addition to clinical sonographer role

b) Tutor sonographer

c) Chief sonographer

d) Clinical supervisor/assessor

e) University lecturer

………

……..

20. Do you in the course of your daily clinical workload, demonstrate how to image or measure a structure or organ with ultrasound to a qualified colleague or student sonographer?

    a) Yes

    b) No

    c) Not applicable as I am not currently employed in a clinical capacity

    d) Other - please specify……
………
……

21. When teaching a clinical scanning skill do you teach the entire skill from beginning to end in one clinical teaching session?

- Yes
- No
- Sometimes

If yes or sometimes, briefly give reasons, why you teach the entire skill in one clinical teaching session?
………
………

If No- briefly describe, why you do not teach the entire skill in one clinical teaching session?
………
………

22 When teaching clinical scanning skills do you provide feedback to the student or colleague?

- Yes
- No
- Sometimes.

If **yes** briefly discuss the **types** of comments you provide to the learner and **timing (when)** you provide the feedback (i.e. during and/or at the conclusion of skill practice)
………
………

If **no** briefly list reasons why?
………
………

23 Does your teaching style and approach change if you are teaching a student or qualified accredited sonographer?

- YES

- NO

- Sometimes

Briefly describe why?

………
……..

24. Do you have any further comments to make on this research topic? Please comment

………
………
………
………
………
………
………
………
……..

STOP your stopwatch NOW

25. Please record the time required to complete the survey? ………….. minutes

Dent, J. A., & Harden, R. M. (2009). *A Practical Guide for Medical Teachers* (Third ed.). Edingurgh: Churchill Livingstone.

Appendix 4: Diagram depicting the percentage of sonographers who reported that they used phantoms to teach psychomotor scanning skills.

The error bar depicts the 5th and the 95th centile confidence intervals.
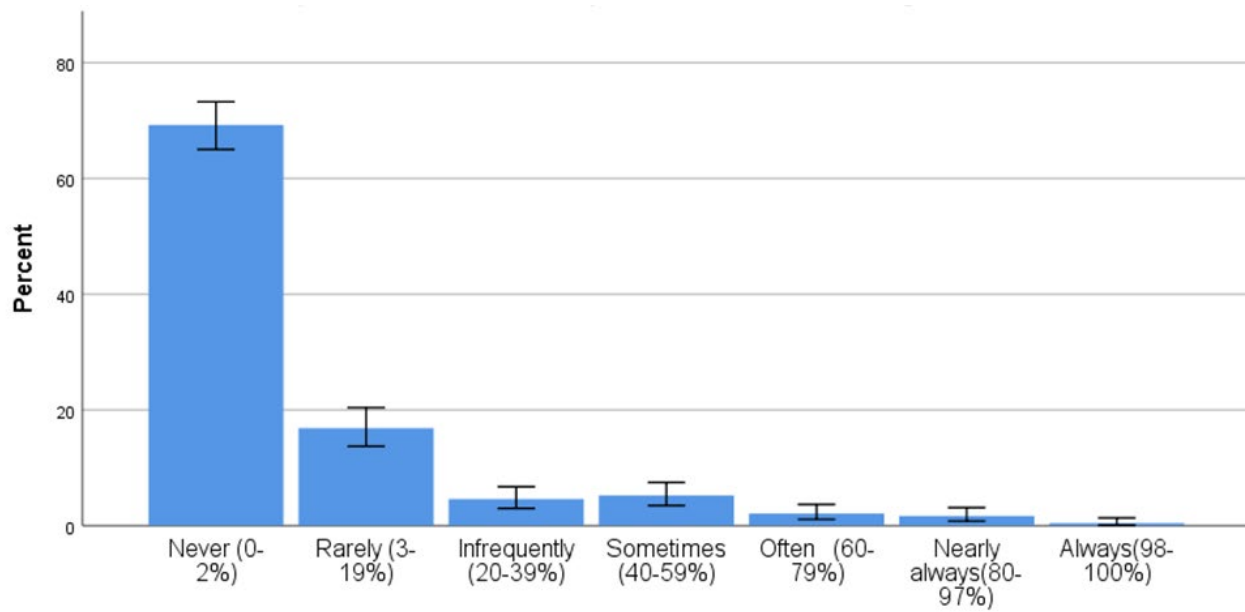
Appendix 5: Diagram depicting the percentage of sonographers who use staff members to teach scanning skills.

The error bar depicts the 5th and the 95th centile confidence intervals.
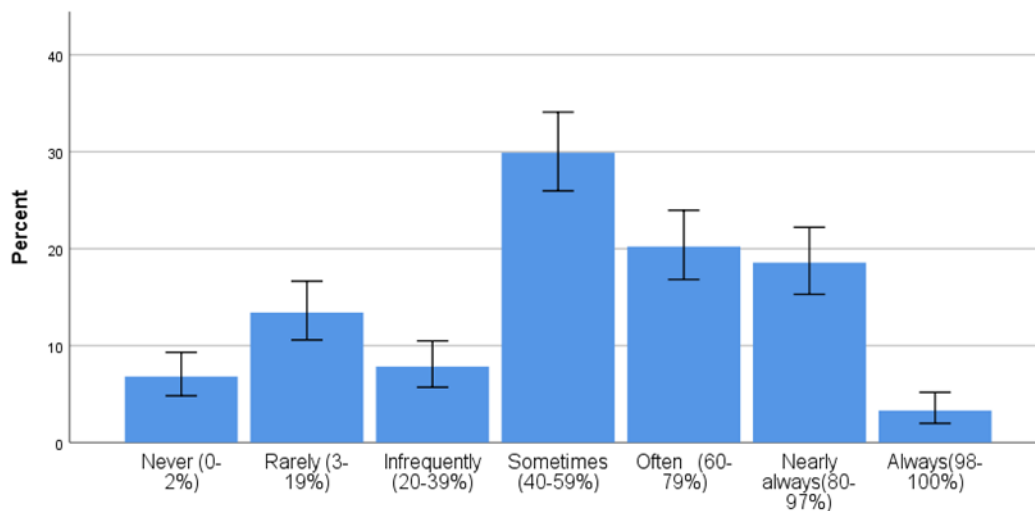
Appendix 6: Frequency distribution, using a seven-point Likert type rating scale, of the respondent's practice behaviours to question 13 which explores how psychomotor skills are being taught.

The table includes the 5th and 95th centile confidence intervals for each item in question 13.

		1.00 Never (0-2%)	2.00 Rarely (3-19%)	3.00 Infrequently (20-39%)	4.00 Sometimes (40-59%)	5.00 Often (60-79%)	6.00 Nearly always (80-97%)	7.00 Always (98-100%)	Total
Use a published STM	Count	148	76	70	96	54	38	27	509
	Row N %	**29.1%**	**14.9%**	**13.8%**	**18.9%**	**10.6%**	**7.5%**	**5.3%**	100.0%
	95.0% Lower CL for Row N %	25.3%	12.0%	11.0%	15.6%	8.2%	5.4%	3.6%	.
	95.0% Upper CL for Row N %	33.1%	18.2%	16.9%	22.4%	13.5%	10.0%	7.5%	.
Prior knowledge	Count	5	5	14	50	118	134	196	522
	Row N %	1.0%	1.0%	2.7%	9.6%	22.6%	25.7%	37.5%	100.0%
	95.0% Lower CL for Row N %	0.4%	0.4%	1.5%	7.3%	19.2%	22.1%	33.5%	.
	95.0% Upper CL for Row N %	2.1%	2.1%	4.3%	12.3%	26.3%	29.5%	41.8%	.
Silent skill demonstration	Count	98	84	57	80	80	77	41	517
	Row N %	19.0%	16.2%	11.0%	15.5%	15.5%	14.9%	7.9%	100.0%
	95.0% Lower CL for Row N %	15.8%	13.3%	8.5%	12.6%	12.6%	12.0%	5.8%	.
	95.0% Upper CL for Row N %	22.5%	19.6%	13.9%	18.8%	18.8%	18.2%	10.5%	.
Narrate-demonstrate	Count	10	7	13	40	120	185	145	520
	Row N %	1.9%	1.3%	2.5%	7.7%	23.1%	35.6%	27.9%	100.0%
	95.0% Lower CL for Row N %	1.0%	0.6%	1.4%	5.6%	19.6%	31.6%	24.2%	.
	95.0% Upper CL for Row N %	3.4%	2.6%	4.1%	10.2%	26.8%	39.8%	31.9%	.
Demonstrate-learner describe	Count	72	81	73	110	81	68	32	517
	Row N %	13.9%	15.7%	14.1%	21.3%	15.7%	13.2%	6.2%	100.0%
	95.0% Lower CL for Row N %	11.1%	12.7%	11.3%	17.9%	12.7%	10.4%	4.4%	.
	95.0% Upper CL for Row N %	17.1%	19.0%	17.3%	25.0%	19.0%	16.3%	8.5%	.

Describe- perform	Count	44	55	66	105	115	95	41	521
	Row N %	8.4%	10.6%	12.7%	20.2%	22.1%	18.2%	7.9%	100.0%
	95.0% Lower CL for Row N %	6.3%	8.1%	10.0%	16.9%	18.7%	15.1%	5.8%	.
	95.0% Upper CL for Row N %	11.1%	13.4%	15.7%	23.8%	25.8%	21.7%	10.4%	.
Immediate error correction	Count	9	5	17	76	106	172	135	520
	Row N %	1.7%	1.0%	3.3%	14.6%	20.4%	33.1%	26.0%	100.0%
	95.0% Lower CL for Row N %	0.9%	0.4%	2.0%	11.8%	17.1%	29.1%	22.3%	.
	95.0% Upper CL for Row N %	3.1%	2.1%	5.1%	17.8%	24.0%	37.2%	29.9%	.
Immediate performance of skill after error correction	Count	8	11	18	66	106	165	146	520
	Row N %	1.5%	2.1%	3.5%	12.7%	20.4%	31.7%	28.1%	100.0%
	95.0% Lower CL for Row N %	0.7%	1.1%	2.1%	10.0%	17.1%	27.8%	24.3%	.
	95.0% Upper CL for Row N %	2.9%	3.6%	5.3%	15.8%	24.0%	35.8%	32.1%	.
guidance & coaching	Count	3	2	1	35	97	184	197	519
	Row N %	0.6%	0.4%	0.2%	6.7%	18.7%	35.5%	38.0%	100.0%
	95.0% Lower CL for Row N %	0.2%	0.1%	0.0%	4.8%	15.5%	31.4%	33.9%	.
	95.0% Upper CL for Row N %	1.5%	1.2%	0.9%	9.1%	22.2%	39.6%	42.2%	.
Long skill practice	Count	65	71	74	89	76	92	50	517
	Row N %	12.6%	13.7%	14.3%	17.2%	14.7%	17.8%	9.7%	100.0%
	95.0% Lower CL for Row N %	9.9%	11.0%	11.5%	14.1%	11.8%	14.7%	7.3%	.
	95.0% Upper CL for Row N %	15.6%	16.9%	17.5%	20.6%	17.9%	21.3%	12.4%	.
Short skill practice	Count	13	31	34	109	138	126	63	514
	Row N %	2.5%	6.0%	6.6%	21.2%	26.8%	24.5%	12.3%	100.0%
	95.0% Lower CL for Row N %	1.4%	4.2%	4.7%	17.8%	23.2%	20.9%	9.6%	.
	95.0% Upper CL for Row N %	4.2%	8.3%	9.0%	24.9%	30.8%	28.4%	15.3%	.
Use a silent video/exemplar	Count	379	53	40	24	14	8	2	520
	Row N %	72.9%	10.2%	7.7%	4.6%	2.7%	1.5%	0.4%	100.0%
	95.0% Lower CL for Row N %	68.9%	7.8%	5.6%	3.1%	1.6%	0.7%	0.1%	.
	95.0% Upper CL for Row N %	76.6%	13.0%	10.2%	6.7%	4.4%	2.9%	1.2%	.

Appendix 7: Frequency distribution, using a seven-point Likert type rating scale, of the respondent's practice behaviours to the items in question 14 of the SonoSTePs survey.

The table includes the 5th and 95th centile confidence intervals for each of the seven Likert rating scales.

		Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly always (80-97%)	Always (98-100%)	Total
K. Use phantoms to teach scanning skills?	Count	333	81	22	25	10	8	2	481
	Row N %	69.2%	16.8%	4.6%	5.2%	2.1%	1.7%	0.4%	100.0%
	95.0% Lower CL for Row N %	65.0%	13.7%	3.0%	3.5%	1.1%	0.8%	0.1%	.
	95.0% Upper CL for Row N %	73.2%	20.4%	6.7%	7.5%	3.7%	3.1%	1.3%	.
J. Use staff members as scan models to teach scanning skills?	Count	33	65	38	145	98	90	16	485
	Row N %	6.8%	13.4%	7.8%	29.9%	20.2%	18.6%	3.3%	100.0%
	95.0% Lower CL for Row N %	4.8%	10.6%	5.7%	26.0%	16.8%	15.3%	2.0%	.
	95.0% Upper CL for Row N %	9.3%	16.6%	10.5%	34.1%	24.0%	22.2%	5.2%	.
I. When teaching a QUALIFIED sonographer a new skill, do you scan first, followed by them?	Count	48	85	46	107	60	98	40	484
	Row N %	9.9%	17.6%	9.5%	22.1%	12.4%	20.2%	8.3%	100.0%
	95.0% Lower CL for Row N %	7.5%	14.4%	7.1%	18.6%	9.7%	16.9%	6.1%	.
	95.0% Upper CL for Row N %	12.8%	21.1%	12.4%	26.0%	15.6%	24.0%	11.0%	.
H. When supervising an ADVANCED student, do they scan the patient before you do?	Count	12	13	15	54	92	199	101	486
	Row N %	2.5%	2.7%	3.1%	11.1%	18.9%	40.9%	20.8%	100.0%
	95.0% Lower CL for Row N %	1.4%	1.5%	1.8%	8.5%	15.6%	36.6%	17.4%	.
	95.0% Upper CL for Row N %	4.1%	4.4%	4.9%	14.1%	22.6%	45.4%	24.6%	.
	Count	20	22	18	61	86	140	139	486

G. When teaching a NOVICE, do you scan the patient first, followed by the learner?	Row N %	4.1%	4.5%	3.7%	12.6%	17.7%	28.8%	28.6%	100.0%
	95.0% Lower CL for Row N %	2.6%	2.9%	2.3%	9.8%	14.5%	24.9%	24.7%	.
	95.0% Upper CL for Row N %	6.2%	6.7%	5.7%	15.7%	21.3%	32.9%	32.7%	.
F. When teaching a new skill, assist learner's scanning, by holding and guiding their scanning hand?	Count	12	31	30	99	123	125	65	485
	Row N %	2.5%	6.4%	6.2%	20.4%	25.4%	25.8%	13.4%	100.0%
	95.0% Lower CL for Row N %	1.4%	4.5%	4.3%	17.0%	21.6%	22.0%	10.6%	.
	95.0% Upper CL for Row N %	4.2%	8.8%	8.6%	24.2%	29.4%	29.8%	16.6%	.
E. Progressively practice Sub-parts to whole skill practice?	Count	15	23	30	100	139	122	51	480
	Row N %	3.1%	4.8%	6.3%	20.8%	29.0%	25.4%	10.6%	100.0%
	95.0% Lower CL for Row N %	1.8%	3.1%	4.3%	17.4%	25.0%	21.7%	8.1%	.
	95.0% Upper CL for Row N %	5.0%	7.0%	8.7%	24.6%	33.1%	29.5%	13.6%	.
D. Teach a sub-part of the total scanning skill?	Count	13	22	30	125	133	116	45	484
	Row N %	2.7%	4.5%	6.2%	25.8%	27.5%	24.0%	9.3%	100.0%
	95.0% Lower CL for Row N %	1.5%	3.0%	4.3%	22.1%	23.6%	20.3%	7.0%	.
	95.0% Upper CL for Row N %	4.4%	6.7%	8.6%	29.9%	31.6%	27.9%	12.1%	.
C. Break a skill down into discrete or sub parts before teaching it?	Count	15	23	23	103	141	130	50	485
	Row N %	3.1%	4.7%	4.7%	21.2%	29.1%	26.8%	10.3%	100.0%
	95.0% Lower CL for Row N %	1.8%	3.1%	3.1%	17.8%	25.2%	23.0%	7.8%	.
	95.0% Upper CL for Row N %	4.9%	6.9%	6.9%	25.0%	33.2%	30.9%	13.3%	.
B. Teach the whole skill	Count	52	67	101	146	70	35	17	488
	Row N %	10.7%	13.7%	20.7%	29.9%	14.3%	7.2%	3.5%	100.0%

at the first teaching session?	95.0% Lower CL for Row N %	8.2%	10.9%	17.3%	26.0%	11.4%	5.1%	2.1%	.
	95.0% Upper CL for Row N %	13.6%	17.0%	24.5%	34.1%	17.7%	9.7%	5.4%	.
A. Change your teaching approach when teaching a student or accredited sonographer?	Count	27	43	27	104	116	105	65	487
	Row N %	5.5%	8.8%	5.5%	21.4%	23.8%	21.6%	13.3%	100.0%
	95.0% Lower CL for Row N %	3.8%	6.6%	3.8%	17.9%	20.2%	18.1%	10.5%	.
	95.0% Upper CL for Row N %	7.8%	11.6%	7.8%	25.2%	27.8%	25.4%	16.6%	.

Appendix 8: The distribution of frequency responses to the rating scale items in question 16.

The 5th and 95th centile confidence intervals are identified for each Likert rating scale category.

		Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly Always (80-97%)	Always (98-100%)	Total
K. End feedback session with positive comment(s)	Count	3	1	3	29	78	176	191	481
	Row N %	0.6%	0.2%	0.6%	6.0%	16.2%	36.6%	39.7%	100.0%
	95.0% Lower CL for Row N %	0.2%	0.0%	0.2%	4.2%	13.1%	32.4%	35.4%	.
	95.0% Upper CL for Row N %	1.7%	1.0%	1.7%	8.4%	19.7%	41.0%	44.1%	.
J. Provide a summary of skill performance and identify performance areas for learner to focus on?	Count	16	26	34	81	109	129	84	479
	Row N %	3.3%	5.4%	7.1%	16.9%	22.8%	26.9%	17.5%	100.0%
	95.0% Lower CL for Row N %	2.0%	3.7%	5.1%	13.8%	19.2%	23.1%	14.3%	.
	95.0% Upper CL for Row N %	5.2%	7.7%	9.7%	20.5%	26.7%	31.0%	21.1%	.
I. Identify what aspects of skill performance could be improved and how?	Count	4	6	15	68	143	145	100	481
	Row N %	0.8%	1.2%	3.1%	14.1%	29.7%	30.1%	20.8%	100.0%
	95.0% Lower CL for Row N %	0.3%	0.5%	1.8%	11.2%	25.8%	26.2%	17.3%	.
	95.0% Upper CL for Row N %	2.0%	2.6%	5.0%	17.5%	33.9%	34.4%	24.6%	.
H. Ask the learner to identify what could be improved and how?	Count	12	27	54	101	125	114	48	481
	Row N %	2.5%	5.6%	11.2%	21.0%	26.0%	23.7%	10.0%	100.0%
	95.0% Lower CL for Row N %	1.4%	3.8%	8.6%	17.5%	22.2%	20.1%	7.5%	.
	95.0% Upper CL for Row N %	4.2%	7.9%	14.3%	24.8%	30.0%	27.7%	12.9%	.

G. State what was done well and why?	Count	3	5	17	56	146	156	100	483
	Row N %	0.6%	1.0%	3.5%	11.6%	30.2%	32.3%	20.7%	100.0%
	95.0% Lower CL for Row N %	0.2%	0.4%	2.1%	9.0%	26.3%	28.2%	17.3%	.
	95.0% Upper CL for Row N %	1.6%	2.3%	5.4%	14.7%	34.4%	36.6%	24.5%	.
F. Ask the learner what was done well and why?	Count	17	50	62	128	104	87	35	483
	Row N %	3.5%	10.4%	12.8%	26.5%	21.5%	18.0%	7.2%	100.0%
	95.0% Lower CL for Row N %	2.1%	7.9%	10.1%	22.7%	18.0%	14.8%	5.2%	.
	95.0% Upper CL for Row N %	5.4%	13.3%	16.0%	30.6%	25.4%	21.6%	9.8%	.
E. Ask for an overview of skill performance or how they felt they went?	Count	19	43	64	128	121	75	33	483
	Row N %	3.9%	8.9%	13.3%	26.5%	25.1%	15.5%	6.8%	100.0%
	95.0% Lower CL for Row N %	2.5%	6.6%	10.4%	22.7%	21.3%	12.5%	4.8%	.
	95.0% Upper CL for Row N %	6.0%	11.7%	16.5%	30.6%	29.1%	19.0%	9.3%	.
D. Deliver feedback using a model to guide delivery and content?	Count	176	99	61	79	35	20	9	479
	Row N %	36.7%	20.7%	12.7%	16.5%	7.3%	4.2%	1.9%	100.0%
	95.0% Lower CL for Row N %	32.5%	17.2%	10.0%	13.4%	5.2%	2.7%	0.9%	.
	95.0% Upper CL for Row N %	41.1%	24.5%	15.9%	20.0%	9.9%	6.3%	3.4%	.
C. Limit feedback in the presence of the patient?	Count	7	19	20	124	106	125	80	481
	Row N %	1.5%	4.0%	4.2%	25.8%	22.0%	26.0%	16.6%	100.0%
	95.0% Lower CL for Row N %	0.7%	2.5%	2.6%	22.0%	18.5%	22.2%	13.5%	.
	95.0% Upper CL for Row N %	2.8%	6.0%	6.2%	29.8%	25.9%	30.0%	20.2%	.

B. Provide feedback at the CONCLUSION of a skill performance?	Count	4	6	13	58	136	156	111	484
	Row N %	0.8%	1.2%	2.7%	12.0%	28.1%	32.2%	22.9%	100.0%
	95.0% Lower CL for Row N %	0.3%	0.5%	1.5%	9.3%	24.2%	28.2%	19.4%	.
	95.0% Upper CL for Row N %	2.0%	2.5%	4.4%	15.1%	32.2%	36.5%	26.8%	.
A. Provide feedback DURING skill performance?	Count	15	34	49	140	130	89	25	482
	Row N %	3.1%	7.1%	10.2%	29.0%	27.0%	18.5%	5.2%	100.0%
	95.0% Lower CL for Row N %	1.8%	5.0%	7.7%	25.1%	23.2%	15.2%	3.5%	.
	95.0% Upper CL for Row N %	5.0%	9.6%	13.1%	33.2%	31.1%	22.1%	7.4%	.

Appendix 9: National Survey SonoSTePs data – Pattern matrix and Factor Analysis

```
* Parallel Analysis Program for Raw Data and Data Permutations.

* This program conducts parallel analyses on data files in which
  the rows of the data matrix are cases/individuals and the
  columns are variables; Data are read/entered into the program
  using the GET command (see the GET command below); The GET
  command reads an SPSS systemfile, which can be either the
  current, active SPSS data file or a previously saved systemfile;
  A valid filename/location must be specified on the GET command;
  A subset of variables for the analyses can be specified by using
  the "/ VAR =" subcommand with the GET statement; There can be
  no missing values.

* You must also specify:
  -- the # of parallel data sets for the analyses;
  -- the desired percentile of the distribution and random
     data eigenvalues;
  -- whether principal components analyses or principal axis/common
     factor analysis are to be conducted, and
  -- whether normally distributed random data generation or
     permutations of the raw data set are to be used in the
     parallel analyses.

* WARNING: Permutations of the raw data set are time consuming;
  Each parallel data set is based on column-wise random shufflings
  of the values in the raw data matrix using Castellan's (1992,
  BRMIC, 24, 72-77) algorithm; The distributions of the original
  raw variables are exactly preserved in the shuffled versions used
  in the parallel analyses; Permutations of the raw data set are
  thus highly accurate and most relevant, especially in cases where
  the raw data are not normally distributed or when they do not meet
  the assumption of multivariate normality (see Longman & Holden,
  1992, BRMIC, 24, 493, for a Fortran version); If you would
  like to go this route, it is perhaps best to (1) first run a
  normally distributed random data generation parallel analysis to
  familiarize yourself with the program and to get a ballpark
  reference point for the number of factors/components;
  (2) then run a permutations of the raw data parallel analysis
  using a small number of datasets (e.g., 10), just to see how long
  the program takes to run; then (3) run a permutations of the raw
  data parallel analysis using the number of parallel data sets that
  you would like use for your final analyses; 1000 datasets are
  usually sufficient, although more datasets should be used if
  there are close calls.


* These next commands generate artificial raw data
  (50 cases) that can be used for a trial-run of
  the program, instead of using your own raw data;
  Just select and run this whole file; However, make sure to
  delete these commands before attempting to run your own data.




set mxloops=9000 printback=off width=80 seed = 1953125.
```

Sequence Plot

Model Description

Model Name		MOD_1
Series or Sequence	1	rawdata
	2	means
	3	percntyl
Transformation		None
Non-Seasonal Differencing		0
Seasonal Differencing		0
Length of Seasonal Period		No periodicity
Horizontal Axis Labels		root
Intervention Onsets		None
For Each Observation		Values not joined

Applying the model specifications from MOD_1

Case Processing Summary

		rawdata	means	percntyl
Series or Sequence Length		30	30	30
Number of Missing Values in the Plot	User-Missing	0	0	0
	System-Missing	0	0	0
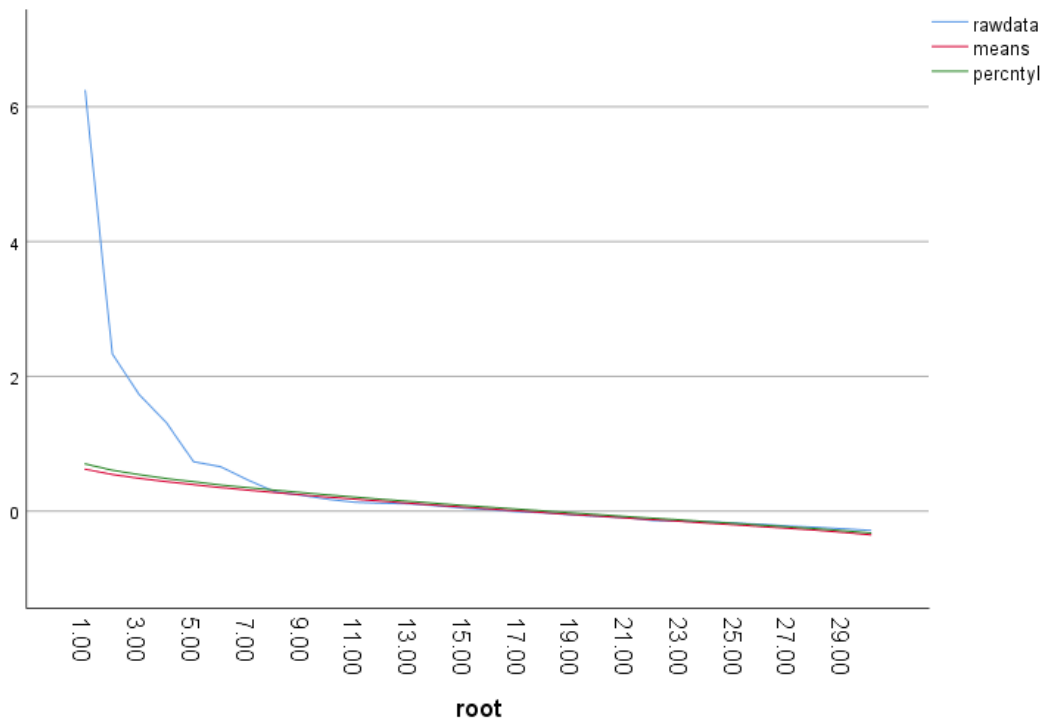
KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.841
Bartlett's Test of Sphericity	Approx. Chi-Square	4868.940
	df	561
	Sig.	.000

Communalities

	Initial	Extraction
Use a published STM	.211	.172
Prior knowledge	.224	.208
Silent skill demonstration	.136	.082
Narrate-demonstrate	.369	.320
Demonstrate-learner describe	.465	.429
Describe- perform	.513	.444
Immediate error correction	.311	.346
Immediate performance of skill after error correction	.476	.472
guidance & coaching	.477	.548
Long skill practice	.281	.200
Use a silent video/exemplar	.303	.312
B. Teach the whole skill at the first teaching session?	.324	.325
C. Break a skill down into discrete or sub parts before teaching it?	.671	.720
D. Teach a sub part of the total scanning skill?	.770	.824
E. Progressively practice sub parts to whole skill practice?	.741	.798
F. When teaching a new skill, assist learner's scanning, by holding and guiding their scanning hand?	.211	.154
K. Use phantoms to teach scanning skills?	.195	.137
A. Provide feedback DURING skill performance?	.325	.225
B. Provide feedback at the CONCLUSION of a skill performance?	.287	.261
C. Limit feedback in the presence of the patient ?	.290	.112

D. Deliver feedback using a model to guide delivery and content?	.333	.304
E. Ask for an overview of skill performance or how they felt they went?	.561	.565
F. Ask the learner what was done well and why?	.699	.712
G. State what was done well and why?	.608	.643
H. Ask the learner to identify what could be improved and how?	.661	.635
I. Identify what aspects of skill performance could be improved and how?	.632	.602
J. Provide a summary of skill performance and identify performance areas for learner to focus on?	.456	.415
K. End feedback session with positive comment (s)	.436	.409

Extraction Method: Principal Axis Factoring.

	Initial	Extraction
Use a published STM	1.000	.285
Prior knowledge	1.000	.257
Silent skill demonstration	1.000	.117
Narrate-demonstrate	1.000	.380
Demonstrate-learner describe	1.000	.497
Describe- perform	1.000	.495
Immediate error correction	1.000	.426
Immediate performance of skill after error correction	1.000	.511
guidance & coaching	1.000	.588
Long skill practice	1.000	.253
Short skill practice	1.000	.144
Use a silent video/exemplar	1.000	.403
A. Change your teaching approach when teaching a student or accredited sonographer?	1.000	.091

B. Teach the whole skill at the first teaching session?	1.000	.511
C. Break a skill down into discrete or sub parts before teaching it?	1.000	.768
D. Teach a sub part of the total scanning skill?	1.000	.820
E. Progressively practice sub parts to whole skill practice?	1.000	.824
F. When teaching a new skill, assist learner's scanning, by holding and guiding their scanning hand?	1.000	.238
G. When teaching a NOVICE, do you scan the patient first, followed by the learner?	1.000	.143
H. When supervising an ADVANCED student, do they scan the patient before you do?	1.000	.188
I. When teaching a QUALIFIED sonographer, a new skill, do you scan first, followed by them?	1.000	.074
J. Use staff members as scan models to teach scanning skills?	1.000	.070
K. Use phantoms to teach scanning skills?	1.000	.227
A. Provide feedback DURING skill performance?	1.000	.410
B. Provide feedback at the CONCLUSION of a skill performance?	1.000	.372
C. Limit feedback in the presence of the patient?	1.000	.286
D. Deliver feedback using a model to guide delivery and content?	1.000	.424
E. Ask for an overview of skill performance or how they felt they went?	1.000	.614

F. Ask the learner what was done well and why?	1.000	.704
G. State what was done well and why?	1.000	.667
H. Ask the learner to identify what could be improved and how?	1.000	.651
I. Identify what aspects of skill performance could be improved and how?	1.000	.629
J. Provide a summary of skill performance and identify performance areas for learner to focus on?	1.000	.470
K. End feedback session with positive comment (s)	1.000	.470

Extraction Method: Principal Component Analysis.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.924	20.366	20.366	6.924	20.366	20.366
2	2.839	8.350	28.717	2.839	8.350	28.717
3	2.374	6.981	35.698	2.374	6.981	35.698
4	1.869	5.498	41.195	1.869	5.498	41.195
5	1.491	4.384	45.580			
6	1.393	4.097	49.677			
7	1.262	3.713	53.390			
8	1.130	3.324	56.714			
9	1.037	3.051	59.765			
10	.983	2.893	62.658			
11	.896	2.636	65.293			
12	.866	2.548	67.841			
13	.845	2.485	70.326			
14	.830	2.440	72.766			
15	.805	2.368	75.135			
16	.750	2.206	77.341			
17	.695	2.045	79.386			
18	.650	1.913	81.298			
19	.624	1.836	83.134			
20	.574	1.688	84.822			
21	.571	1.680	86.501			
22	.533	1.568	88.069			

23	.481	1.414	89.484			
24	.469	1.378	90.862			
25	.462	1.358	92.219			
26	.403	1.186	93.405			
27	.401	1.181	94.586			
28	.385	1.132	95.717			
29	.338	.994	96.711			
30	.302	.887	97.598			
31	.280	.823	98.422			
32	.225	.663	99.085			
33	.170	.499	99.583			
34	.142	.417	100.000			

Extraction Method: Principal Component Analysis.

Component Matrix[a]

	Component			
	1	2	3	4
Use a published STM	.227	.334	.262	.231
Prior knowledge	.461			
Silent skill demonstration		.207		
Narrate-demonstrate	.523		-.204	.246
Demonstrate-learner describe	.384	.381	.306	.333
Describe- perform	.487	.357		.305
Immediate error correction	.487			.400
Immediate performance of skill after error correction	.620			.329
guidance & coaching	.594		-.392	.258
Long skill practice	.427			.226
Short skill practice	.317			
Use a silent video/exemplar	.273	.430	.375	
A. Change your teaching approach when teaching a student or accredited sonographer?	.201			
B. Teach the whole skill at the first teaching session?		.565	-.437	
C. Break a skill down into discrete or sub parts before teaching it?	.500	-.602	.392	
D. Teach a sub part of the total scanning skill?	.465	-.628	.452	

	Col 1	Col 2	Col 3	Col 4
E. Progressively practice sub parts to whole skill practice?	.465	-.632	.450	
F. When teaching a new skill, assist learner's scanning, by holding and guiding their scanning hand?	.362			.281
G. When teaching a NOVICE, do you scan the patient first, followed by the learner?	.275	-.254		
H. When supervising an ADVANCED student, do they scan the patient before you do?	.251		-.267	
I. When teaching a QUALIFIED sonographer, a new skill, do you scan first, followed by them?	.233			
J. Use staff members as scan models to teach scanning skills?				
K. Use phantoms to teach scanning skills?		.322	.319	
A. Provide feedback DURING skill performance?	.302		-.309	.471
B. Provide feedback at the CONCLUSION of a skill performance?	.448		-.366	
C. Limit feedback in the presence of the patient?	.216			-.456
D. Deliver feedback using a model to guide delivery and content?	.343	.325	.446	
E. Ask for an overview of skill performance or how they felt they went?	.640		.204	-.357
F. Ask the learner what was done well and why?	.681	.281		-.387
G. State what was done well and why?	.698		-.304	-.291
H. Ask the learner to identify what could be improved and how?	.682	.253		-.331

I. Identify what aspects of skill performance could be improved and how?	.736			-.238
J. Provide a summary of skill performance and identify performance areas for learner to focus on?	.626			-.213
K. End feedback session with positive comment (s)	.574		-.312	

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Structure Matrix

	Factor			
	1	2	3	4
guidance & coaching	.726			-.330
Immediate performance of skill after error correction	.652			-.314
Immediate error correction	.566			
Narrate-demonstrate	.549			
K. End feedback session with positive comment (s)	.515			-.470
A. Provide feedback DURING skill performance?	.459			
B. Provide feedback at the CONCLUSION of a skill performance?	.402			-.365
Prior knowledge	.392			-.328
Long skill practice	.355		.310	
F. When teaching a new skill, assist learner's scanning, by holding and guiding their scanning hand?	.316			
D. Teach a sub part of the total scanning skill?		-.901		
E. Progressively practice sub parts to whole skill practice?		-.884		
C. Break a skill down into discrete or sub parts before teaching it?		-.833		-.303
B. Teach the whole skill at the first teaching session?		.513		
Demonstrate-learner describe			.633	

	1	2	3	4
Describe- perform	.381		.596	
Use a silent video/exemplar			.549	
D. Deliver feedback using a model to guide delivery and content?			.509	
Use a published STM			.410	
K. Use phantoms to teach scanning skills?			.361	
Silent skill demonstration				
F. Ask the learner what was done well and why?			.425	-.804
H. Ask the learner to identify what could be improved and how?			.415	-.758
G. State what was done well and why?	.503			-.734
I. Identify what aspects of skill performance could be improved and how?	.496			-.726
E. Ask for an overview of skill performance or how they felt they went?			.396	-.708
J. Provide a summary of skill performance and identify performance areas for learner to focus on?	.390			-.604
C. Limit feedback in the presence of the patient?				

Extraction Method: Principal Axis Factoring.

Rotation Method: Oblimin with Kaiser Normalization.

Factor Correlation Matrix

Factor	1	2	3	4
1	1.000	-.123	.155	-.325
2	-.123	1.000	-.048	.229
3	.155	-.048	1.000	-.233
4	-.325	.229	-.233	1.000

Extraction Method: Principal Axis Factoring.

Rotation Method: Oblimin with Kaiser Normalization.

In Australia, how does the ultrasound profession teach psychomotor scanning skills required for clinical practice?

Thank you for participating in this online study at SurveyMonkey. Your participation in this survey is voluntary and all data cannot be identified or traced back to you.

Please make a note of **your start and finish time** and **record the completion time on the last page,** to complete the survey. However, as a guide, it is anticipated that the survey will take approximately 20 minutes.

You have been invited to participate in a national profession-based survey, which aims to garner a broad base of data and information about how sonographers teach   scanning skills in the clinical environment. There is little published data on this subject. The survey is exploring how sonographers (in their practices and in more formal teaching environments) teach scanning skills and provide information on skill practice. In particular, the survey is aiming to:

- e) Establish sonographer skill teaching practices
- f) Explore whether sonographers in daily clinical practice identify with the implicit role of skills teacher and feedback provider.
- g) Identify if sonographers utilise elements of published skills teaching and feedback models being utilised by other health professions, to teach clinical skills.
- h) Establish whether simulation and simulated skill teaching activities are used to assist scanning skill development

Highlight- start your stopwatch NOW

Demographic and professional practice information

2.   Please indicate you gender.
- c) Male
- d) Female

3.   What is your age?

    Please type your age in years………

4.   Select the state or territory that you perform clinical ultrasound?

- j) NSW
- k) ACT

l)   QLD

m) VIC

n)   SA

o)   WA

p)   Tasmania

q)   Northern Territory (NT)

r)   Multiple states and Northern Territory (locum)

4. Select the location which you are employed at **the most clinical hours** per week as a sonographer?

    f)   Private practice

    g) Public Hospital

    h) Private Hospital

    i)   Equal private practice and public hospital practice

    j)   Nil- I am not employed in a clinical capacity

5. Which area of sonographic practice do you work the **majority** of your clinical hours? (Please select just one response)

    i)   General sonography

    j)   Cardiac sonography

    k) Obstetric and Gynaecological sonography

    l)   Breast sonography

    m) Vascular sonography

    n) Paediatric sonography

    o) Nil- I am not employed in a clinical capacity

    p) Other   (please specify)…….

6. Which of the following categories best describes your employment status?

    a) Part-time (less than 35 hours per week)

    b) Full-time

    c) On long service leave

    d) On maternity or parental leave

    e) Locum part time

    f) Other, please specify………………………………………………………………………………….

7. Which category best describes your **PRIMARY PLACE** of clinical practice?

e) I work as a solo sonographer at a single sonographer practice location

f) I work with two or more sonographers

g) I work as a locum sonographer in varying clinical practices

h) Other, please specify……………………………………………………………………….

8. What is the highest level of qualification in **ultrasound** you have completed?

h) On the job training with grandfather credentialing

i) TAFE certificate in ultrasound

j)   Diploma of Medical Ultrasound-Australian Society for Ultrasound in Medicine (DMU)

k) Graduate Diploma

l) Master in Ultrasound

m) PhD

n) Prefer not to answer

9. Which of the following categories best describes your **primary role** when employed in medical ultrasound?

f) Clinical sonographer (primary role is to scan patients)

g) Tutor sonographer

h) Chief sonographer

i) Clinical supervisor/assessor

j) University lecturer

Sonographer skills teaching and feedback practice

Simulation based ultrasound skill education, is a teaching/learning context which utilises simulative aides to teach and foster scanning skill development. Examples of simulation learning aides include plastic manikins, animal models, human cadavers and simulated or standardised patients (Dent and Harden, 2009)

11. Do you teach scanning skills using simulated learning models? Please select one or more options below:
- Students
- Colleagues
- No compulsory to move to question 11

If yes please provide details of the type of simulative learning aides you employ to teach scanning skills…………………………………………………………………………………………………

……………………………………………………………………………………………………….

……………………………………………………………………………………………………….

15. You have identified that you do not use simulative aides to teach psychomotor scanning skills. What are the main reasons that you do not use these tools/models to teach scanning skills?
    - The purchase cost of phantoms or simulative aides
    - The cost to hire a simulated patient is expensive and unaffordable
    - The department cannot get funding to purchase a simulative teaching tool
    - The simulative teaching tools do not provide value for money as they need to be replaced every 5-10 years
    - I have not considered this option for the department
    - I do not know how to teach scanning skills on a phantom, so I have not purchased a simulative aide

Please provide additional information if the above responses have not been able to solicit why you do not teach psychomotor scanning skills using a simulative learning tool.

……
……
………..

16. Do you change your skill teaching approach when teaching scanning skills using simulative learning aides?
    - Yes
    - Sometimes
    - No

If Yes or sometimes, what aspects of your skill teaching approach do you change and briefly explain why ?..
....
....

13. When teaching scanning skills using simulated learning tools, do you teach these skills in a:
    f) Private practice
    g) Public hospital
    h) University teaching setting
    i) Private training/tutoring institution
    j) Other, please specify………………………………………………………………………………………
       ………………………………………………………………………………………………

14. **Please select an answer for each question**. When teaching a sonographer an ultrasound scanning skill, do you?

	Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly Always (80-97%)	Always (98-100%)

A Teach a scanning skill using a published teaching model?						
B. Teach the theoretical knowledge to support the skill execution prior to physically teaching the skill?						
C. Establish the learner's prior knowledge on the skill topic?						
D. Commence by silently demonstrating the skill?						
E. Repeat the demonstration whilst describing the skill steps?						
F. Repeat demonstration whilst the learner describes the skill steps?						
G Ask the learner to describe the skill steps as they demonstrate the skill?						
H. Correct skill performance errors immediately they occur?						
I. After correcting a skill error, ask the learner to re-perform the skill or task correctly?						
J. Provide **verbal** guidance and coaching **during** skill performance?						
K. Provide skill practise opportunities in						

long practice sessions (more than 60 minutes)?							
L. Provide skill practice opportunities **in short practice** sessions (less than 60 minutes)?							
M. Provide a silent video of skill demonstration for teaching purposes?							

15. **Please select an answer for each question**. When teaching a scanning skill on a patient or imaging phantom, to a sonographer do you?

	Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly Always (80-97%)	Always (98-100%)
A. Change your teaching approach when teaching a student or accredited sonographer?							
B. Teach how to position the patient, select the acoustic window, scan and perform the necessary image optimisation in the one teaching session?							
C. Teach the whole skill at the first teaching session?							
D. Break a skill down into discrete or sub parts before teaching it?							
E. Teach a sub part of the total scanning skill?							

F Progressively practice sub parts to whole skill practice?							
G. When teaching a new skill, assist learners scanning, by holding and guiding their scanning hand?							
H. When teaching a **novice**, you scan the patient first, followed by the learner?							
I. When supervising an **advanced student**, do they scan the patient before you do?	.						
J. When teaching a qualified **sonographer,** a new skill, do you scan first, followed by them?							
K. Use staff members as scan models to teach scanning skills?							
L. Use phantoms to teach scanning skills?							

16 Please select an answer for each question. In a skill teaching setting, when you OBSERVE a scanning skill performance, do you?

	Never (0-2%)	Rarely (3-19%)	Infrequently (20-39%)	Sometimes (40-59%)	Often (60-79%)	Nearly always (80-97%)	Always (98-100%)
A. Provide feedback during skill performance??							

B. Provide feedback at the **conclusion** of a skill performance?						
C. Limit feedback in presence of patient?						
D. A Deliver feedback using a model to guide delivery and content?						
E. Ask for an overview of skill performance or how they felt they went?						
F. Ask the learner what was done well and why?						
G. State what was done well and why?						
H. Ask the learner to identify what could be improved and how?						
I. Identify what aspects of skill performance could be improved and how?						
J. Provide a summary of skill performance and identify performance areas for learner to focus on?						
K. End feedback session with positive comment (s)						

Experiences as a learner and teacher

17. Have you completed extra training in health education, such as completing the "train the trainer" course or sonographer education/training workshops/courses conducted at national conference?

- Yes
- No

If yes please specify………
………
………

18. What is the highest level of qualification in **health education i.e. teaching/training qualifications,** you have completed?

       h) None

       i) Graduate certificate

       j) Graduate Diploma

       k) Master by coursework

       l) PhD

       m) Master by research

       n) Prefer not to answer

19. Select which **teaching/training** roles you perform **in addition** to your primary clinical sonographer role?

       f) No- I do not perform additional clinical teaching/training roles in addition to clinical sonographer role

       g) Tutor sonographer

       h) Chief sonographer

       i) Clinical supervisor/assessor

       j) University lecturer

         ………
         ………..

20. Do you in the course of your daily clinical workload, demonstrate how to image or measure a structure or organ with ultrasound to a qualified colleague or student sonographer?

       e) Yes

       f) No

       g) Not applicable as I am not currently employed in a clinical capacity

       h) Other - please specify…………………………………………………………………………………………
         ……
         ……

21. When teaching a clinical scanning skill do you teach the entire skill from beginning to end in one clinical teaching session?

- Yes
- No
- Sometimes

If yes or sometimes, briefly give reasons, why you teach the entire skill in one clinical teaching session?

……

………………………………………………………………………………………………………..

If No- briefly describe, why you do not teach the entire skill in one clinical teaching session?

……

………………………………………………………………………………………………………..

22. Prior to teaching a scanning skill, do you teach the theoretical knowledge, related to the execution of the psychomotor scanning skill, skill using a didactic lecture format? Please select one answer.

- Yes
- No
- Sometimes

Briefly explain why you do or do not use this teaching approach?...

....

....

23. When teaching clinical scanning skills do you provide feedback to the student or colleague?

- Yes
- No
- Sometimes.

If **yes** briefly discuss the **types** of comments you provide to the learner and **timing (when)** you provide the feedback (i.e. during and/or at the conclusion of skill practice)

……

……

………………………………………………………………………………………………………

If **no** briefly list reasons why?

……

……

………………………………………………………………………………………………………

24 Does your teaching style and approach change if you are teaching a student or qualified accredited sonographer?

- YES
- NO
- Sometimes

Briefly describe why?

 ……..
……
……..

25 Do   you   have   any   further   comments   to   make   on   this   research   topic?   Please
comment   ………
……
……
……
……
……
……
……
……
……
……

STOP your stopwatch NOW

26. Please record the time required to complete the survey? ………….. minutes

Dent, J. A., & Harden, R. M. (2009). *A Practical Guide for Medical Teachers* (Third ed.). Edingurgh:
       Churchill Livingstone.

REFERENCE LIST

Abela, J. (2009). Adult learning theories and medical education: A review. *Malta Medical Journal, 21*(1), 11-18.

Adams, J. A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3*(2), 111-149. doi:10.1080/00222895.1971.10734898

Aggarwal, R., Grantcharov, T., Moorthy, K., Hance, J., & Darzi, A. (2006). A competency-based virtual reality training curriculum for the acquisition of laparoscopic psychomotor skill. *American Journal of Surgery, 191*(1), 128-133. doi:10.1016/j.amjsurg.2005.10.014

Aggarwal, R., Grantcharov, T. P., & Darzi, A. (2007). Framework for systematic training and assessment of technical skills. *Journal of the American College of Surgeons, 204*(4), 697-705. doi:10.1016/j.jamcollsurg.2007.01.016

Ahmed, O. M. A., Azher, I., Gallagher, A. G., Breslin, D. S., O'Donnell, B. D., & Shorten, G. D. (2018). Deliberate practice using validated metrics improves skill acquisition in performance of ultrasound-guided peripheral nerve block in a simulated setting. *Journal of Clinical Anesthesia, 48*, 22-27. doi:10.1016/j.jclinane.2018.04.015

Alzayedi, A. S., Azizalrahman, A. A., AlMadi, H. A., Althekair, A. M., Blaivas, M., & Karakitsos, D. (2017). Use and education of point-of-care ultrasound in pediatric emergency medicine in Saudi Arabia. *Journal of Ultrasound in Medicine, 36*(11), 2219-2225. doi:10.1002/jum.14254

American Institute of Ultrasound in, M. (2005). Transducer manipulation for echocardiography. *Journal of Ultrasound in Medicine, 24*(5), 733-736. doi:10.7863/jum.2005.24.5.733

American Institute of Ultrasound in Medicine. (1999). AIUM technical bulletin. Transducer manipulation. American Institute of Ultrasound in Medicine. *Journal of Ultrasound in Medicine, 18*(2), 169-175. doi:10.7863/jum.1999.18.2.169

Anderson, A. (1997). Learning strategies in physical education: Self-talk, imagery, and goal-setting. *Journal of Physical Education, Recreation & Dance, 68*(1), 30-35.

Anderson, L. A., & Sharpe, P. A. (1991). Improving patient and provider communication: A synthesis and review of communication interventions. *Patient Education and Counseling, 17*(2), 99-134. doi:10.1016/0738-3991(91)90014-v

Archer, E., van Hoving, D. J., & de Villiers, A. (2015). In search of an effective teaching approach for skill acquisition and retention: Teaching manual defibrillation to junior medical students. *African Journal of Emergency Medicine, 5*(2), 54-59. doi:10.1016/j.afjem.2014.10.009

Arger, P. H., Schultz, S. M., Sehgal, C. M., Cary, T. W., & Aronchick, J. (2005). Teaching medical students diagnostic sonography. *Journal of Ultrasound in Medicine, 24*(10), 1365-1369. doi:10.7863/jum.2005.24.10.1365

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19-32. doi:10.1080/1364557032000119616

Aspegren, K. (1999). BEME GUIDE no.2: Teaching and learning communication skills in medicine-A review with quality grading of articles. *Medical Teacher, 21*(6), 563-570.

Australasian Society for Ultrasound in Medicine. (1976). Neonatal head ultrasound. Retrieved from http://www.asum.com.au/about-the-australasian-society-for-ultrasound-in-medicine/history-of-medical-ultrasound/#25a57c5f2cfc049f7

Australasian Society for Ultrasound in Medicine. (1978). Research octoson. Retrieved from http://www.asum.com.au/about-the-australasian-society-for-ultrasound-in-medicine/history-of-medical-ultrasound/#25a57c5f2cfc049f7

Australasian Sonographers Association. (2011). ASA competency standards for the entry level sonographer. Retrieved from http://www.sonographers.org/public/12/files/Our_Profession/ASA_Competency-Standards_Nov09.pdf

Australasian Sonographers Association. (2015). ASA guideline: A sonographer's guide to clinical supervision. Retrieved from http://www.sonographers.org/public/12/files/Guidelines/Clinical_Supervision_ASA-Guidline_Nov15.pdf

Australian Government. (2018). Area of Australia: States and Territories.

Australian Government Department of Human Services. (2017). Medicare Australia statistics.

Australian Sonographer Accreditation Registry (ASAR) (2011). [Sonographers accredited in Australia-November 2011].

Australian Sonography Accreditation Registry (2014a, 5/11/2014). [2014 Australian qualified sonographer workforce data].

Australian Sonography Accreditation Registry. (2014b). ASAR accredited qualified Australian sonographers: Gender 2008-2012.

Bahner, D. P., Adkins, E. J., Hughes, D., Barrie, M., Boulger, C. T., & Royall, N. A. (2013). Integrated medical school ultrasound: Development of an ultrasound vertical curriculum. *Critical Ultrasound Journal, 5*(1), 6. doi:10.1186/2036-7902-5-6

Bahner, D. P., Blickendorf, J. M., Bockbrader, M., Adkins, E., Vira, A., Boulger, C., & Panchal, A. R. (2016). Language of transducer manipulation: Codifying terms for effective teaching. *Journal of Ultrasound in Medicine, 35*(1), 183-188. doi:10.7863/ultra.15.02036

Bahner, D. P., Goldman, E., Way, D., Royall, N. A., & Liu, Y. T. (2014). The state of ultrasound education in U.S. medical schools: Results of a national survey. *Academic Medicine, 89*(12), 1681-1686. doi:10.1097/ACM.0000000000000414

Bahner, D. P., Hughes, D., & Royall, N. A. (2012). I-AIM: A novel model for teaching and performing focused sonography. *Journal of Ultrasound in Medicine, 31*(2), 295-300. doi:10.7863/jum.2012.31.2.295

Baker, J. P. (2005). The history of sonographers. *Journal of Ultrasound in Medicine, 24*(1), 1-14. doi:10.7863/jum.2005.24.1.1

Barnett, K., Mercer, S. W., Norbury, M., Watt, G., Wyke, S., & Guthrie, B. (2012). Epidemiology of multimorbidity and implications for health care, research, and medical education: A cross-sectional study. *Lancet, 380*(9836), 37-43. doi:10.1016/S0140-6736(12)60240-2

Bartlett, M. S. (1954). A note on the multiplying factors for chi square approximations. *Journal of The Royal Statistical Society, 16 (series B)*, 296-298.

Bearman, M., Anthony, A., & Nestel, D. (2011). A pilot training program in surgical communication, leadership and teamwork. *ANZ Journal of Surgery, 81*(4), 213-215. doi:10.1111/j.1445-2197.2011.05673.x

Beckstead, J. W. (2014). On measurements and their quality. Paper 4: Verbal anchors and the number of response options in rating scales. *International Journal of Nursing Studies, 51*(5), 807-814. doi:10.1016/j.ijnurstu.2013.09.004

Berkhof, M., van Rijssen, H. J., Schellart, A. J., Anema, J. R., & van der Beek, A. J. (2011). Effective training strategies for teaching communication skills to physicians: an overview of systematic reviews. *Patient Education and Counseling, 84*(2), 152-162. doi:10.1016/j.pec.2010.06.010

Bjerrum, F., Maagaard, M., Led Sorensen, J., Rifbjerg Larsen, C., Ringsted, C., Winkel, P., Ottesen, B., & Strandbygaard, J. (2015). Effect of instructor feedback on skills retention after laparoscopic simulator training: Follow-up of a randomized trial. *Journal of Surgical Education, 72*(1), 53-60. doi:10.1016/j.jsurg.2014.06.013

Bjork, I. T. (1997). Changing conceptions of practical skill and skill acquisition in nursing education. *Nursing Inquiry, 4*(3), 184-195. doi:10.1111/j.1440-1800.1997.tb00098.x

Bleakley, A. (2002). Pre-registration house officers and ward-based learning: A 'new apprenticeship' model. *Medical Education, 36*(1), 9-15. doi:10.1046/j.1365-2923.2002.01128.x

Blissett, S., Cavalcanti, R., & Sibbald, M. (2012). Should we teach using schemas? Evidence from a randomised trial. *Medical Education, 46*, 815-822.

Boud, D., & Molloy, E. (2013). Rethinking models of feedback for learning: The challenge of design. *Assessment & Evaluation in Higher Education, 38*(6), 698-712. doi:10.1080/02602938.2012.691462

Brovelli, A., Laksiri, N., Nazarian, B., Meunier, M., & Boussaoud, D. (2008). Understanding the neural computations of arbitrary visuomotor learnign through fMRI and associative learning theory. *Cerebral Cortex, 18*, 1485-1495.

Brown, C., Cartwright, L., Craig, J., Meredith, T., Musial, U., Orzelek, S., Pacey, A., Searle, S., Cox, L., Halldorf, M., Jubb, C., & Ruediger, D. (2011). Clinical supervision in echocardiography: A review of the cardiac sonographer role when mentoring the student. *Sound Effects, 2*, 12-15.

Brydges, R., Carnahan, H., Backstein, D., & Dubrowski, A. (2007). Application of motor learning principles to complex surgical tasks: Searching for the optimal practice schedule. *Journal of Motor Behavior, 39*(1), 40-48. doi:10.3200/JMBR.39.1.40-48

Buchanan, E. A., & Hvizdak, E. E. (2009). Online survey tools: Ethical and methodological concerns of human research ethics committees. *Journal of Empirical Research on Human Research Ethics, 4*(2), 37-48. doi:10.1525/jer.2009.4.2.37

Burton, G., & Dimbleby, R. (1990). *Teaching communication*. London, GBR: Routledge.

Bylund, C. L., Brown, R. F., di Ciccone, B. L., Levin, T. T., Gueguen, J. A., Hill, C., & Kissane, D. W. (2008). Training faculty to facilitate communication skills training: Development and evaluation of a workshop. *Patient Education and Counseling, 70*(3), 430-436. doi:10.1016/j.pec.2007.11.024

Cartier, R. A., 3rd, Skinner, C., & Laselle, B. (2014). Perceived effectiveness of teaching methods for point of care ultrasound. *The Journal of Emergency Medicine, 47*(1), 86-91. doi:10.1016/j.jemermed.2014.01.027

Castanelli, D. J. (2009). The rise of simulation in technical skills teaching and the implications for training novices in anaesthesia. *Anaesthesia and Intensive Care, 37*(6), 903-910. doi:10.1177/0310057X0903700605

Catana, S. E. (2014). Teaching cross-cultural communication issues–A way of successfully integrating into the multicultural knowledge society. *Procedia - Social and Behavioral Sciences, 128*, 343-348. doi:10.1016/j.sbspro.2014.03.168

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research, 1*(2), 245-276. doi:10.1207/s15327906mbr0102_10

Chapman, E., Hagen, S., & Gallagher, H. (2016). Is there a relationship between ultrasound scanning ability (sonography) and visuospatial perception or psychomotor ability? *Ultrasound, 24*(4), 214-221. doi:10.1177/1742271X16674039

Chenkin, J., Lee, S., Huynh, T., & bandiera, G. (2008). Procedures can be learned on the web: A randomized study of ultrasound-guided vascular access training. *Academic Emergency Medicine, 15*(10), 949-954.

Clark, R. E., Pugh, C. M., Yates, K. A., Inaba, K., Green, D. J., & Sullivan, M. E. (2012). The use of cognitive task analysis to improve instructional descriptions of procedures. *Journal of Surgical Research, 173*(1), e37-42. doi:10.1016/j.jss.2011.09.003

Cleland, J., & Durning, S. (2015). *Researching medical education*. Chichester, UK: John Wiley & Sons.

Cohen, J. W. (1988). *Statistical power and analysis for the behavioural sciences* (Second ed.). Hillsdale, New Jersey: Laurence Erlbaum Associates

Cornford, I. R. (1999). Skill learning and the development of expertise. In J. Athanasou (Ed.), *Adult Educational Psychology*: Social Science Press.

Cosyns, B., De Diego, J. J., Stefanidis, A., Galderisi, M., Ernande, L., Underwood, S. R., Bucciarelli-Ducci, C., Lancellotti, P., & Habib, G. (2015). E-learning in cardiovascular imaging: Another step towards a structured educational approach. *European Heart Journal - Cardiovascular Imaging, 16*(5), 463-465. doi:10.1093/ehjci/jev022

Craig, M. (2016). What it takes to be a good clinical instructor. *Journal of Diagnostic Medical Sonography, 14*(4), 172-176. doi:10.1177/875647939801400405

Creswell, J. (2008). *Educational research. planning, conducting, and evaluating quantitative and qualitative research* (Third ed.). Upper Saddle River, New Jersey: Pearson Prentice Hall.

Crofts, G. (2015). A framework for guiding learning in ultrasound scanning. *Ultrasound, 23*(1), 6-10. doi:10.1177/1742271X14562228

Cronbach, L. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*, 297–334.

Cushing, A. M. (2015). Learning patient-centred communication: The journey and the territory. *Patient Education and Counseling, 98*(10), 1236-1242. doi:10.1016/j.pec.2015.07.024

D'Agostino, M. A., & Schmidt, W. A. (2013). Ultrasound-guided injections in rheumatology: Actual knowledge on efficacy and procedures. *Best Practice and Research: Clinical Rheumatology, 27*(2), 283-294. doi:10.1016/j.berh.2013.04.001

Davies, S. (2018a, 28/3/2018). [Clinical skill teaching approaches used by the Australian pioneers of medical ultrasound].

Davies, S. (2018b, 28/3/2018). [The scanning techniques required by the sonographer to use and operate the Unirad and Advanced Diagnostic Resolution ultrasound machines].

Davis, J. J., Wessner, C. E., Potts, J., Au, A. K., Pohl, C. A., & Fields, J. M. (2018). Ultrasonography in undergraduate medical education: A systematic review. *Journal of Ultrasound in Medicine, 37*(11), 2667-2679. doi:10.1002/jum.14628

De Vaus, D. A. (2002). *Surveys in social research* (Fifth ed.). Sydney, Australia: Allen & Unwin.

De Vellis, R. F. (2012). *Scale development theory and applications* (L. Bickman & D. Rog Eds. Third ed.). Los Angeles: Sage.

DeBourgh, G. A. (2011). Psychomotor skills acquisition of novice learners: A case for contextual learning. *Nurse Educator, 36*(4), 144-149. doi:10.1097/NNE.0b013e31821fdab1

Dent, J. A., & Harden, R. M. (2009). *A practical guide for medical teachers* (Third ed.). Edinburgh: Churchill Livingstone.

Dent, J. A., Harden, R. M., & Hunt, D. (2017). *A practical guide for medical teachers* (Fifth ed.). Edinburgh: Elsevier.

DesCoteaux, J. G., & Leclere, H. (1995). Learning surgical technical skills. *Canadian Journal of Surgery, 38*(1), 33-38.

DeVellis, R. (2017). *Scale development theory and applications* (Fourth ed.). Thousand Oaks, California: Sage.

Deveugele, M. (2015). Communication training: Skills and beyond. *Patient Education and Counseling, 98*(10), 1287-1291. doi:10.1016/j.pec.2015.08.011

Deveugele, M., Derese, A., De Maesschalck, S., Willems, S., Van Driel, M., & De Maeseneer, J. (2005). Teaching communication skills to medical students, a challenge in the curriculum? *Patient Education and Counseling, 58*(3), 265-270. doi:10.1016/j.pec.2005.06.004

DeYoung, S. (2003). *Teaching strategies for nurse educators*. Upper Saddle River, New Jersey Prentice Hall.

Dillman, D., Smyth, J., & Christian, L. (2014). *Internet, phone, mail, and mixed-mode surveys. The tailored design mode* (Fourth ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Dizon, J. M., & Grimmer-Somers, K. (2011). Complex interventions required to comprehensively educate allied health practitioners on evidence-based practice. *Advances in Medical Education and Practice, 2*, 105-108. doi:10.2147/AMEP.S19767

Doyon, J., & Benali, H. (2005). reorganization and plasticity in the adult brain during learning of motor skills. *Current Opinion in Neurobiology, 15*, 161-167.

Dresang, L. T., Rodney, W. M., & Dees, J. (2004). Teaching prenatal ultrasound to family medicine residents. *Family Medicine, 36*(2), 98-107.

Dreyfus, S. E. (2016). The five-stage model of adult skill acquisition. *Bulletin of Science, Technology & Society, 24*(3), 177-181. doi:10.1177/0270467604264992

Edwards, E., Chamunyonga, C., & Clarke, J. (2018). The role of deliberate practice in development of essential sonography skills. *Sonography, 5*(2), 76-81. doi:10.1002/sono.12146.

Efron, B., & Tibshirani, R. (1986). Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. *Statistical Science, 1*(1), 54-57.

Ende, J. (1983). Feedback in clinical medical education. *JAMA, 250*(6), 777-781.

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological review, 100*, 364-406.

Evans, J. R., & Mathur, A. (2005). The value of online surveys. *Internet Research, 15*(2), 195-219. doi:10.1108/10662240510590360

Evans, J. R., & Mathur, A. (2018). The value of online surveys: A look back and a look ahead. *Internet Research, 28*(4), 854-887. doi:10.1108/IntR-03-2018-0089

Faarvang, K. L., & Ringsted, C. (2006). A six-step approach to teaching physical examination. *Medical Education, 40*(5), 475. doi:10.1111/j.1365-2929.2006.02461.x

Feygin, D., Keehner, M., & Tendick, R. (2002, 2002). *Haptic guidance: Experimental evaluation of a haptic training method for a perceptual motor skill.* Paper presented at the HAPTICS 2002. 10th Symposium Orlando, Florida, USA.

Fish, P. (1990). *Physics and instrumentation of diagnostic medical ultrasound*. Chichester: John Wiley & Sons.

Fitts, P. M. (1962). *Factors in complex skill training*. Pittsburgh: University of Pittsburgh Press.

Fitts, P. M., & Posner, M. I. (1967). *Human performance*. Belmont, CA: Brooks/Cole.

Foy, H. (2009). Teaching technical skills-Errors in the process. In S. R. T. Evans (Ed.), *Surgical Pitfalls* (pp. 11-22). Philadelphia: W.B. Saunders.

Gaitini, D., & Dahiya, N. (2012). The shoulder rotator cuff pathology and beyond. *Ultrasound Clinics, 7*, 425-438.

Gentile, A. M. (1972). A working model of skill acquisition with application to teaching. *Quest, 17*, 3-23.

George, J. H., & Doto, F. X. (2001). A simple five-step method for teaching technical skills. *Family Medicine, 33*, 577-578.

Gibbs, V. (2014). An investigation into sonography student experiences of simulation teaching and learning in the acquisition of clinical skills. *Ultrasound, 22*(3), 173-178. doi:10.1177/1742271X14528491

Gibbs, V. (2015). The role of ultrasound simulators in education: An investigation into sonography student experiences and clinical mentor perceptions. *Ultrasound, 23*(4), 204-211. doi:10.1177/1742271X15604665

Gidley Larson, J. C., & Suchy, Y. (2015). The contribution of verbalization to action. *Psychological Research, 79*(4), 590-608. doi:10.1007/s00426-014-0586-0

Gill, R. (2012). *Physics and technology of diagnostic ultrasound: A practitioner's guide*. Sydney: High Frequency Publishing.

Gill, R. (2018). Medical ultrasound in Australia: A short history. *Australasian Journal of Ultrasound in Medicine, 21*(1), 3-8. doi:10.1002/ajum.12085

Grantcharov, T., & Reznick, R. (2008). Teaching rounds: Teaching procedural skills. *British Medical Journal, 336*, 1129-1131.

Green, J., & Thorogood, N. (2018). *Qualitative methods for health research* (Fourth ed.). London: Sage publications.

Greenstein, Y. Y., Littauer, R., Narasimhan, M., Mayo, P. H., & Koenig, S. J. (2017). Effectiveness of a critical care ultrasonography course. *Chest, 151*(1), 34-40. doi:10.1016/j.chest.2016.08.1465

Greif, R., Egger, L., Basciani, R. M., Lockey, A., & Vogt, A. (2010). Emergency skill training-A randomized controlled study on the effectiveness of the 4-stage approach compared to traditional clinical teaching. *Resuscitation, 81*(12), 1692-1697. doi:10.1016/j.resuscitation.2010.09.478

Griffiths, K. (2004). An historical look at ultrasound as an Australian innovation on the occasion of the Ultrasound stamp issued by Australia Post- 18 May 2004. *ASUM Ultrasound Bulletin, 7*(3), 22-26.

Hamdorf, J. M., & Hall, J. C. (2000). Acquiring surgical skills. *British Journal of Surgery, 87*(1), 28-37. doi:10.1046/j.1365-2168.2000.01327.x

Hammond, I., & Karthigasu, K. (2006). Training, assessment and competency in gynaecologic surgery. *Best Practice & Research Clinical Obstetrics and Gynaecology, 20*(1), 173-187. doi:10.1016/j.bpobgyn.2005.09.006

Harrow, A. J. (1972). *A taxonomy of the psychomotor domain*. NewYork: David McKay.

Hassal, L. (2007). Sonography-The emergence of a profession. *ASUM Ultrasound Bulletin, 10*(3), 29-34.

Heaven, C., Clegg, J., & Maguire, P. (2006). Transfer of communication skills training from workshop to workplace: The impact of clinical supervision. *Patient Education and Counseling, 60*(3), 313-325. doi:10.1016/j.pec.2005.08.008

Hewlett, S. (2018, 22/2/2018). [History of ultrasound in Australia].

Hoffman, S. J. (1990). Relevance, application, and the development of an unlikely theory. *Quest, 42*(2), 143-160.

Horn, J. L. (1965). A rationale and test for the number of factors in factor analysis. *Psychometrika, 30*, 179-185. doi:10.1007/bf02289447

Hume, C., Ball, K., & Salmon, J. (2006). Development and reliability of a self-report questionnaire to examine children's perceptions of the physical activity environment at home and in the neighbourhood. *International Journal of Behavioral Nutrition and Physical Activity, 3*, 16. doi:10.1186/1479-5868-3-16

Jabbour, N., Reihsen, T., Sweet, R. M., & Sidman, J. D. (2011). Psychomotor skills training in pediatric airway endoscopy simulation. *Otolaryngology– Head and Neck Surgery, 145*(1), 43-50. doi:10.1177/0194599811403379

Jamison, R., Hovancsek, M., & Clochesy, J. (2006). A pilot study assessing simulation using two simulation methods for teaching intravenous cannulation. *Clinical Simulation in Nursing Education, 2*, e9-e12.

Jayawardene, A., & LaDuca, T. (2014). Addressing physicians' poor communication skills in Sri Lanka. *Medical Education, 48*(5), 540-541. doi:10.1111/medu.12461

Johnson, B., & Christensen, L. (2012). *Educational research-Quantitative, qualitative, and mixed approaches* (Fourth ed.). Los Angeles: Sage.

Kai, J. (2005). Cross-cultural communication. *Medicine, 33*(2), 31-34. doi:10.1383/medc.33.2.31.58386

Kaiser, H. (1974). An index of factorial simplicity *Psychometrika, 39* 31–36.

Kantak, S. S., & Winstein, C. J. (2012). Learning-performance distinction and memory processes for motor skills: A focused review and perspective. *Behavioural Brain Research, 228*(1), 219-231. doi:10.1016/j.bbr.2011.11.028

Kaye, B. K., & Johnson, T. J. (2016). Research methodology: Taming the cyber frontier. *Social Science Computer Review, 17*(3), 323-337. doi:10.1177/089443939901700307

Kleim, J. A., Hogg, T. M., VandenBerg, P. M., Cooper, N. R., Bruneau, R., & Remple, M. (2004). Cortical synaptogenesis and motor map reorganization occur during late, but not early, phase of motor skill learning. *The Journal of Neuroscience, 24*(3), 628-633.

Kneebone, R. (1999). Twelve tips on teaching basic surgical skills using simulation and multimedia. *Medical Teacher, 21*(6), 571-575. doi:10.1080/01421599978988.

Kneebone, R. (2003). Simulation in surgical training: Educational issues and practical implications. *Medical Education, 37*(3), 267-277. doi:10.1046/j.1365-2923.2003.01440.x

Kneebone, R., Kidd, J., Nestel, D., Asvall, S., Paraskeva, P., & Darzi, A. (2002). An innovative model for teaching and learning clinical procedures. *Medical Education, 36*(7), 628-634. doi:10.1046/j.1365-2923.2002.01261.x

Kneebone, R. L., Nestel, D., Vincent, C., & Darzi, A. (2007). Complexity, risk and simulation in learning procedural skills. *Medical Education, 41*(8), 808-814. doi:10.1111/j.1365-2923.2007.02799.x

Kolb, D. A. (2015). *Experiential learning: Experience as the source of learning and development* (Second ed.). Upper Saddle River, New Jersey: Pearson Education, Inc.

Kovacs, G. (1997). Procedural skills in medicine: linking theory to practice. *The Journal of Emergency Medicine, 15*(3), 387-391. doi:10.1016/s0736-4679(97)00019-x

Krause, D., Brune, A., Fritz, S., Kramer, P., Meisterjahn, P., Schneider, M., & Sperber, A. (2014). Learning of a golf putting task with varying contextual interference levels induced by feedback schedule in novices and experts. *Perceptual & Motor Skills: Learning & Memory, 118*(2), 384-399. doi:10.2466/23.30.PMS.118k17w3

Krautter, M., Weyrich, P., Schultz, J. H., Buss, S. J., Maatouk, I., Junger, J., & Nikendei, C. (2011). Effects of Peyton's four-step approach on objective performance measures in technical skills training: A controlled trial. *Teaching and Learning in Medicine, 23*(3), 244-250. doi:10.1080/10401334.2011.586917

Kray, J., Lucenet, J., & Blaye, A. (2010). Can older adults enhance task-switching performance by verbal self instruction? The influence of working-memory load and early learning. *Frontiers in Aging Neuroscience, 2*(147), 1-9. doi:10.3389/fnagi.2010.00147

Kumar, R. (2011). *Research methodology a step-by-step guide for beginners* (Third ed.). London: Sage Publications.

Lake, F. R., & Hamdorf, J. M. (2004). Teaching on the run tips 5: Teaching a skill. *The Medical Journal of Australia, 181*(6), 327-328.

Lammers, R., Davenport, M., Korley, F., Griswold-Theodorson, S., Fitch, M., Narang, A., Evans, L., Gross, A., Rodriguez, E., Dodge, K., Hamann, C., & Robey, W. (2008). Teaching and assessing procedural skills using simulation: Metrics and methodology. *Academic Emergency Medicine, 15*(11), 1079-1087. doi:10.1111/j.1553-2712.2008.00233.x

Lane, C., & Rollnick, S. (2007). The use of simulated patients and role-play in communication skills training: a review of the literature to August 2005. *Patient Education and Counseling, 67*(1-2), 13-20. doi:10.1016/j.pec.2007.02.011

Lavender, I., Coombs, P. R., Van Haltren, K., & Robinson, A. J. (2016). Routine screening for callosal dysgenesis in the second trimester is achievable with intensive training. *Journal of Ultrasound in Medicine, 35*(4), 717-722. doi:10.7863/ultra.15.05069

Leitz, P. (2009). Research into question design. A summary of the literature. *International Journal of Market Research, 52*(2), 249-272. doi:10.2501/S147078530920120X

Leppink, J., & van den Heuvel, A. (2015). The evolution of cognitive load theory and its application to medical education. *Perspectives on Medical Education, 4*(3), 119-127. doi:10.1007/s40037-015-0192-x

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: Advancing the methodology. *Implementation Science, 5*(1), 69. doi:10.1186/1748-5908-5-69

Lucander, H., Knutsson, K., Salé, H., & Jönsson, A. (2012). "I'll never forget this": Evaluating a pilot workshop in effective communication for dental students. *Journal of Dental Education, 76*(10), 1311-1316.

Lynn, M. R. (1986). Determination and quantification of content validity. *Nursing Research, 35*(6), 382-385.

Maatouk-Burmann, B., Ringel, N., Spang, J., Weiss, C., Moltner, A., Riemann, U., Langewitz, W., Schultz, J. H., & Junger, J. (2016). Improving patient-centered communication: Results of a randomized controlled trial. *Patient Education and Counseling, 99*(1), 117-124. doi:10.1016/j.pec.2015.08.012

Maguire, P., & Pitceathly, C. (2002). Key communication skills and how to acquire them. *British Medical Journal, 325*(7366), 697-700. doi:10.1136/bmj.325.7366.697

Masters, R. S., Lo, C. Y., Maxwell, J. P., & Patil, N. G. (2008a). Implicit motor learning in surgery: Implications for multi-tasking. *Surgery, 143*(1), 140-145. doi:10.1016/j.surg.2007.06.018

Masters, R. S., Poolton, J. M., Abernethy, B., & Path, N. (2008b). Implicit learning of movement skills for surgery. *ANZ Journal of Surgery, 78*, 1062-1062.

McLean, G. (2016). Sonographer education in Australia. *Sonography, 3*(4), 123-124. doi:10.1002/sono.12092

Meadley, B., Olaussen, A., Delorenzo, A., Roder, N., Martin, C., St Clair, T., Burns, A., Stam, E., & Williams, B. (2017). Educational standards for training paramedics in ultrasound: A scoping review. *BMC Emergency Medicine, 17*(1), 18. doi:10.1186/s12873-017-0131-8

Meyer, R. A. (2004). History of ultrasound in cardiology. *Journal of Ultrasound in Medicine, 23*(1), 1-11. doi:10.7863/jum.2004.23.1.1

Milde, F. K. (1988). The function of feedback in psychomotor-skill learning. *Western Journal of Nursing Research, 10*(4), 425-434. doi:10.1177/019394598801000406

Miller, G. E. (1990). The assessment of clinical skills/competence/performance. *Academic Medicine, 65*(9 Suppl), S63-67. doi:10.1097/00001888-199009000-00045

Molloy, E. (2009). Time to pause: Giving and receiving feedback in clinical education. In C. Delany & E. Molloy (Eds.), *Clinical education in the health professions* (Vol. 1, pp. 128-146). Sydney, Australia: Churchill Livingstone Elsevier.

Molloy, E. (2010). The feedforward mechanism: A way forward in clinical learning? *Medical Education, 44*(12), 1157-1158. doi:10.1111/j.1365-2923.2010.03868.x

Montealegre-Gallegos, M., Pal, A., & Matyal, R. (2014). Pro: Simulation training in transesophageal echocardiography. *Journal of Cardiothoracic and Vascular Anesthesia, 28*(5), 1410-1411. doi:10.1053/j.jvca.2014.04.032

Moore, C. L., & Copel, J. A. (2011). Point-of-Care ultrasonography. *New England Journal of Medicine, 364*(8), 749-757. doi:10.1056/NEJMra0909487

Moore, G. C., & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research, 2*(3), 192-222. doi:10.1287/isre.2.3.192

Neale, M. L., Chambers, J. L., Kelly, A. T., Connard, S., Lawton, M. A., Roche, J., & Appleberg, M. (1994). Reappraisal of duplex criteria to assess significant carotid stenosis with special reference to reports from the North American symptomatic carotid endarterectomy trial and the European carotid surgery trial. *Journal of Vascular Surgery, 20*(4), 642-649. doi:10.1016/0741-5214(94)90290-9

Nestel, D., Kidd, J., & Kneebone, R. (2003a). Communicating during procedures: Development of a rating scale. *Medical Education, 37*(5), 480-481. doi:10.1046/j.1365-2923.2003.01502_9.x

Nestel, D., Kneebone, R., & Kidd, J. (2003b). Teaching and learning about skills in minor surgery. *Journal of Clinical Nursing, 12*(2), 291-296. doi:10.1046/j.1365-2702.2003.00694.x

Nestel, D., & Kneebone, R. L. (2010). Authentic patient perspectives in simulation for proceedural and surgical skills. *Academic Medicine, 85*(5), 889-892. doi:10.1097/ACM.0b013e3181d749ac

Nicholls, D., Sweet, L., & Hyett, J. (2014). Psychomotor skills in medical ultrasound imaging: An analysis of the core skill set. *Journal of Ultrasound in Medicine, 33*(8), 1349-1352. doi:10.7863/ultra.33.8.1349

Nicholls, D., Sweet, L., Muller, A., & Hyett, J. (2016a). Teaching psychomotor skills in the twenty-first century: Revisiting and reviewing instructional approaches through the lens of contemporary literature. *Medical Teacher, 38*(10), 1056-1063. doi:10.3109/0142159X.2016.1150984

Nicholls, D., Sweet, L., Muller, A., & Hyett, J. (2018). A model to teach concomitant patient communication during psychomotor skill development. *Nurse Education Today, 60*, 121-126. doi:10.1016/j.nedt.2017.09.004

Nicholls, D., Sweet, L., Muller, A., Hyett, J., & Ullah, S. (2017). Continuing development and initial validation of a questionnaire to measure sonographer skill-teaching perceptions in clinical practice. *Journal of Medical Ultrasound, 25*(2), 82-89. doi:10.1016/j.jmu.2017.01.001

Nicholls, D., Sweet, L., Skuza, P., Muller, A., & Hyett, J. (2016b). Sonographer skill teaching practices survey: Development and initial validation of a survey instrument. *Australasian Journal of Ultrasound in Medicine, 19*(3), 109-117. doi:10.1002/ajum.12011

Noble, L. M., Kubacki, A., Martin, J., & Lloyd, M. (2007). The effect of professional skills training on patient-centredness and confidence in communicating with patients. *Medical Education, 41*(5), 432-440. doi:10.1111/j.1365-2929.2007.02704.x

Nunnally, J. O. (1978). *Psychometric theory*. New York: McGraw-Hill.

O'Connell, M., Lieberman, L. J., & Petersen, S. (2006). The use of tactile modelling and physical guidance as instructional strategies in physical activity for children who are blind. *Journal of Visual Impairment and Blindness, 100*(8), 471-477.

Ong, C. C., Dodds, A., & Nestel, D. (2016). Beliefs and values about intra-operative teaching and learning: A case study of surgical teachers and trainees. *Advances in Health Sciences Education. Theory and Practice, 21*(3), 587-607. doi:10.1007/s10459-015-9654-5

Orde, S., Celenza, A., & Pinder, M. (2010). A randomised trial comparing a 4-stage to 2-stage teaching technique for laryngeal mask insertion. *Resuscitation, 81*(12), 1687-1691. doi:10.1016/j.resuscitation.2010.05.026

Payton, O. (1986). *Psychosocial aspects of clinical practice*. New York: Churchill Livingstone.

Pendleton, D., Schofield, T., & Tate, P. (1984). *The consultation: An approach to learning and teaching*. Oxford: Oxford University Press.

Pessin, Y. J., & Tang-Simmons, J. (2017). Testicular phantom use in sonography education: Bridging the classroom and clinical experience. *Journal of Diagnostic Medical Sonography, 33*(4), 261-266. doi:10.1177/8756479317691247

Pett, M. A., Lackey, N. R., & Sullivan, J. J. (2003). *Making sense of factor analysis. The use of factor analysis for instrument development in health care research.* Thousand Oaks, California: Sage.

Phipps, D., Meakin, G. H., Beatty, P. C., Nsoedo, C., & Parker, D. (2008). Human factors in anaesthetic practice: Insights from a task analysis. *British Journal of Anaesthesia, 100*(3), 333-343. doi:10.1093/bja/aem392

Polit, D. F., & Beck, C. T. (2006). The content validity index: Are you sure you know what's being reported? Critique and recommendations. *Researching in Nursing and Health, 29*(5), 489-497. doi:10.1002/nur.20147

Poole, J. L. (1991). Application of motor learning principles in occupational therapy. *The American Journal of Occupational Therapy, 45*(6), 531-537. doi:10.5014/ajot.45.6.531

Pugh, D., Hamstra, S. J., Wood, T. J., Humphrey-Murto, S., Touchie, C., Yudkowsky, R., & Bordage, G. (2015). A procedural skills OSCE: Assessing technical and non-technical skills of internal medicine residents. *Advances in Health Sciences Education. Theory and Practice, 20*(1), 85-100. doi:10.1007/s10459-014-9512-x

Raffi, F., Shaw, R. W., & Amer, S. A. (2012). National survey of the current management of endometriomas in women undergoing assisted reproductive treatment. *Human Reproduction, 27*(9), 2712-2719. doi:10.1093/humrep/des195

Raman, M., & Donnon, T. (2008). Procedural skills education- Colonoscopy as a model. *The Canadian Journal of Gastroenterology, 22*(9), 767-770.

Ramani, S. (2008). Twelve tips for excellent physical examination teaching. *Medical Teacher, 30*(9-10), 851-856. doi:10.1080/01421590802206747

Ramani, S., & Krackov, S. K. (2012). Twelve tips for giving feedback effectively in the clinical environment. *Medical Teacher, 34*(10), 787-791. doi:10.3109/0142159X.2012.684916

Razavi, S. M., Karbakhsh, M., Panah Khahi, M., Dabiran, S., Asefi, S., Shahrak, G. H., & Afrooz, A. R. (2010). Station-based deconstructed training model for teaching procedural skills to medical students: A quasi-experimental study. *Advances in Medical Education and Practice, 1*(1), 17-23. doi:10.2147/AMEP.S13750

Reznick, R., & MacRae, H. (2006). Teaching surgical skills--Changes in the wind. *The New England Journal of Medicine, 355*(25), 2664-2669. doi:10.1056/NEJMra054785

Reznick, R., Regehr, G., MacRae, H., Martin, J., & McCulloch, W. (1997). Testing technical skill via an innovative "bench station" examination. *The American Journal of Surgery, 173*(3), 226-230. doi:10.1016/s0002-9610(97)89597-9

Reznick, R. K. (1993). Teaching and testing technical skills. *American Journal of Surgery, 165*(3), 358-361. doi:10.1016/s0002-9610(05)80843-8

Roberts, S. T., Vignato, J. A., Moore, J. L., & Madden, C. A. (2009). Promoting skill building and confidence in freshman nursing students with a "Skills-a-thon". *The Journal of Nursing Education, 48*(8), 460-464. doi:10.3928/01484834-20090518-05

Rose, M., & Best, D. (2005). *Transforming practice through clinical education, professional supervision, and mentoring.* Edinburgh: Elsevier-Churchhill Livingstone.

Rumack, C., Wilson, S., Charboneau, W., & Levine, D. (Eds.). (2011). *Diagnostic ultrasound* (Fourth ed. Vol. 2). Philadelphia: Elsevier, Mosby.

Ruscio, J., & Roche, B. (2012). Determining the number of factors to retain in an exploratory factor analysis using comparison data of known factorial structure. *Psychological Assessment, 24*(2), 282-292. doi:10.1037/a0025697

Ryan, F. (2017). The clinical education of sonographers: The effective supervision of sonographer trainees. *Sonography, 4*(2), 63-69. doi:10.1002/sono.12102

Saldana, J. (2009). *The coding manual for qualitative researchers* (Second ed.). London: SAGE Publications.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results: A review and critical appraisal. *Psychological Bulletin, 95*(3), 355-386.

Sanders, R., & Hall-Terracciano, B. (2016). *Clinical sonography a practical guide* (Fifth ed.). Philadelphia: Walters Kluwer.

Sarantakos, S. (2005). *Social research* (Third ed.). London: Palgrave Macmillan.

Sarantakos, S. (2013). *Social research* (Fourth ed.). New York: Palgrave Macmillan.

Sattelmayer, M., Elsig, S., Hilfiker, R., & Baer, G. (2016). A systematic review and meta-analysis of selected motor learning principles in physiotherapy and medical education. *BMC Medical Education, 16*, 15. doi:10.1186/s12909-016-0538-z

Schaeffer, N. C., & Dykema, J. (2011). Questions for surveys: Current trends and future directions. *Public Opinion Quarterly, 75*(5), 909-961. doi:10.1093/poq/nfr048

Schleyer, T. K., & Forrest, J. L. (2012). Methods for design and administration of web-based survey. *Journal of American Medical Informatics Association, 7*(4), 416-425.

Schmidt, R. (1975). Motor skill learning. *Psychological review, 82*(4), 225-260.

Schmidt, R. A., Lee, T., Winstein, C., Wulf, G., & Zelaznik, H. (2019). *Motor control and learning: A behavioural emphasis* (Sixth ed.). Champaign, Illinois Human Kinetics.

Schmidt, R. A., & Lee, T. D. (2011). *Motor control and learning: A behavioural emphasis* (Fifth ed.). Loer Mitcham, South Australia, Australia: Human kinetics

Scott, T. E., Thomas, L., Edwards, K., Jones, J., Swan, H., & Wessels, A. (2013). Increasing recognition of fetal heart anatomy using online tutorials and mastery learning compared with classroom instructional methods. *Journal of Diagnostic Medical Sonography, 30*(2), 52-59. doi:10.1177/8756479313517297

Setia, M. S. (2016). Methodology series module 3: Cross-sectional studies. *Indian Journal of Dermatology, 61*(3), 261-264. doi:10.4103/0019-5154.182410

Sewell, J. L., Maggio, L. A., ten Cate, O., van Gog, T., Young, J. Q., & O'Sullivan, P. S. (2019). Cognitive load theory for training health professionals in the workplace: A BEME review of studies among diverse professions: BEME Guide No. 53. *Medical Teacher, 41*(3), 256-270. doi:10.1080/0142159X.2018.1505034

Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin and Review, 20*(1), 21-53. doi:10.3758/s13423-012-0333-8

Silverman, J., & Wood, D. F. (2004). New approaches to learning clinical skills. *Medical Education, 38*(10), 1021-1023. doi:10.1111/j.1365-2929.2004.01978.x

Simpson, E. (1966). *The classification of educational objectives, psychomotor domain*. (BR-5-0090, microfiche, ED 010 368). University of Illinois, Urbana, Illinois.

Sonaggera, T. (2004). Sonography clinical education. *Journal of Diagnostic Medical Sonography, 20*(5), 356-360. doi:10.1177/8756479304268663

Spittle, M. (2013). *Motor learning and skill acquisition: Applications for physical education and sport*. South Yarra, Victoria, Australia: Palgrave Macmillan.

Spruit, E. N., Band, G. P., & Hamming, J. F. (2015). Increasing efficiency of surgical training: Effects of spacing practice on skill acquisition and retention in laparoscopy training. *Surgical Endoscopy and Other Interventional Techniques, 29*(8), 2235-2243. doi:10.1007/s00464-014-3931-x

Spruit, E. N., Band, G. P., Hamming, J. F., & Ridderinkhof, K. R. (2014). Optimal training design for procedural motor skills: A review and application to laparoscopic surgery. *Psychological Research, 78*(6), 878-891. doi:10.1007/s00426-013-0525-5

Stevens, J. (2002). *Applied multivariate statistics for the social sciences* (Fourth ed.). Mahwah, NJ Lawrence Erlbaum Associates

Streiner, D. L., & Norman, G. R. (2008). *Health measurement scales-A practical guide to their development and use* (Fourth ed.). New York: Oxford University Press.

Sullivan, M. E., Brown, C. V., Peyre, S. E., Salim, A., Martin, M., Towfigh, S., & Grunwald, T. (2007). The use of cognitive task analysis to improve the learning of percutaneous tracheostomy placement. *American Journal of Surgery, 193*(1), 96-99. doi:10.1016/j.amjsurg.2006.09.005

Sullivan, M. E., Ortega, A., Wasserberg, N., Kaufman, H., Nyquist, J., & Clark, R. (2008). Assessing the teaching of procedural skills: Can cognitive task analysis add to our traditional teaching methods? *American Journal of Surgery, 195*(1), 20-23. doi:10.1016/j.amjsurg.2007.08.051

Sultan, S. F., Shorten, G., & Iohom, G. (2013). Simulators for training in ultrasound guided procedures. *Medical Ultrasonography, 15*(2), 125-131. doi:10.11152/mu.2013.2066.152.sfs1gs2

Sun, R., Slusarz, P., & Terry, C. (2005). The interaction of the explicit and the implicit in skill learning: A dual-process approach. *Psychological review, 112*(1), 159-192. doi:10.1037/0033-295X.112.1.159

Sutkin, G., Littleton, E. B., & Kanter, S. L. (2015). How surgical mentors teach: A classification of in vivo teaching behaviors part 2: Physical teaching guidance. *Journal of Surgical Education, 72*(2), 251-257. doi:10.1016/j.jsurg.2014.10.004

Swanson, J. O., Kawooya, M. G., Swanson, D. L., Hippe, D. S., Dungu-Matovu, P., & Nathan, R. (2014). The diagnostic impact of limited, screening obstetric ultrasound when performed by midwives in rural Uganda. *Journal of Perinatology, 34*(7), 508-512.

Sweller, J. (1993). Some cognitive processes and their consequences for the organisation and presentation of information. *Australian Journal of Psychology, 45*, 1-8.

Swinnen, S. P., Lee, T. D., Verschueren, S., Serrien, D. J., & Bogaerds, H. (1997). Interlimb coordination: Learning and transfer under different feedback conditions. *Human Movement Science, 16*(6), 749-785. doi:10.1016/s0167-9457(97)00020-1

Tabachnick, B., & Fidell, L. (2007). *Using multivariate statistics* (Fifth ed.). Boston: Pearson Education.

Teutsch, C. (2003). Patient–doctor communication. *Medical Clinics of North America, 87*(5), 1115-1145. doi:10.1016/s0025-7125(03)00066-x

Thoirs, K., & Coffee, J. (2012). Developing the clinical psychomotor skills of musculoskeletal sonography using a multimedia DVD: A pilot study. *Australasian Journal of Educational Technology, 28*(4), 703-718.

Thoirs, K., Osborne, B., Childs, J. T., Parange, N., & Maranna, S. (2016). Skill development of beginner sonography students using high-fidelity simulators: Initial experiences. *Sonography, 3*(1), 5-11. doi:10.1002/sono.12043

Thoirs, K., & Sim, J. (2016). Using a clinical decision-making framework to foster sonographer student learning in the clinical setting. *Sonography, 3*(4), 146-153. doi:10.1002/sono.12074

Thrush, A., & Hartshorne, T. (2005). *Peripheral vascular ultrasound*. Edinburgh: Elsevier Churchill Livingstone.

Vagias, W., M. (2006). *Likert-type scale response anchors*. Clemson University: Clemson International Institute for Tourism and Research Development, Department of Parks, Recreation and Tourism Management.

van der Linden, W. J. (2010). *Handbook of modern item response theory*. New York: Springer-Verlag.

van Merrienboer, J. J., & Sweller, J. (2010). Cognitive load theory in health professional education: design principles and strategies. *Medical Education, 44*(1), 85-93. doi:10.1111/j.1365-2923.2009.03498.x

van Merriënboer, J. J. G., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology, 20*(3), 343-352. doi:10.1002/acp.1250

Victorian State Government: Department of Health and Human Services. (2016). *Victorian allied health workforce research project: Sonography workforce report*. Retrieved from https://www2.health.vic.gov.au/.../%7BB3105094-8CB4-4C15-AD28-A4682E5CC34:

Virdi, M. S., & Sood, M. (2011). Effectiveness of a five-step method for teaching clinical skills to students in a dental college in India. *Journal of Dental Education, 75*(11), 1502-1506.

Walker, M., & Peyton, R. (1998). Teaching in theatre. In R. Peyton (Ed.), *Teaching and learning in medical practice* (pp. 171-180). Rickmansworth, UK: Manticore Europe Limited.

Walsh, C. M., Ling, S. C., Wang, C. S., & Carnahan, H. (2009). Concurrent versus terminal feedback: It may be better to wait. *Academic Medicine, 84*(10 Suppl), S54-57. doi:10.1097/ACM.0b013e3181b38daf

Wang, T. S., Schwartz, J. L., Karimipour, D. J., Orringer, J. S., Hamilton, T., & Johnson, T. M. (2004). An education theory-based method to teach a procedural skill. *Archives of Dermatology, 140*(11), 1357-1361. doi:10.1001/archderm.140.11.1357

Webb, E. M., Cotton, J. B., Kane, K., Straus, C. M., Topp, K. S., & Naeger, D. M. (2014). Teaching point of care ultrasound skills in medical school: Keeping radiology in the driver's seat. *Academic Radiology, 21*(7), 893-901. doi:10.1016/j.acra.2014.03.001

Weisberg, H. F. (2004). Variation ratio. In Lewis-Beck. M, Bryman. A, & Futing Liao. T (Eds.), *The SAGE Encyclopedia of Social Science Research Methods*. Thousand Oaks: SAGE Publications.

Westerway, S. (2018, 12/2/2018). [The history of the developing role of clinical application specialists in Australia].

Wetzel, A. (2013). Factor analysis methods and validity evidence: A review of instrument development across the medical education continuum. *Academic Medicine, 7*(8), 1060-1069.

White, C., Rodger, M. W. M., & Tang, T. (2016). Current understanding of learning psychomotor skills and the impact on teaching laparoscopic surgical skills. *The Obstetrician & Gynaecologist, 18*(1), 53-63. doi:10.1111/tog.12255

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Journal of Emergency Primary Health Care, 8*(3), 1-13.

Winstein, C. J. (1991). Knowledge of results and motor learning-Implications for physical therapy. *Physical Therapy, 71*(2), 140-149. doi:10.1093/ptj/71.2.140

Winstein, C. J., Pohl, P. S., & Lewthwaite, R. (1994). Effects of physical guidance and knowledge of results on motor learning: Support for the guidance hypothesis. *Research Quarterly for Exercise and Sport, 65*(4), 316-323. doi:10.1080/02701367.1994.10607635

Wise, S. P., & Willingham, D. T. (2009). Motor skill learning. In L. R. Squire (Ed.), *Encyclopedia of Neuroscience* (pp. 1057-1066). Oxford: Academic Press.

Woo, J. (1998, November 2006). A short history of the development of ultrasound in obstetrics and gynecology. Part 1. Retrieved from http://www.ob-ultrasound.net/history1.html

Wu, C. C., Maher, M. M., & Shepard, J. A. (2011). Complications of CT - guided percutaneous needle biopsy of the chest: Prevention and management. *American Journal of Roentgenology, 196*(6), W678-682. doi:10.2214/AJR.10.4659

Wulf, G., Shea, C., & Lewthwaite, R. (2010). Motor skill learning and performance: A review of influential factors. *Medical Education, 44*(1), 75-84. doi:10.1111/j.1365-2923.2009.03421.x

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review, 9*(2), 185-211. doi:10.3758/bf03196276

Wulf, G., Shea, C. H., & Matschiner, S. (1998). Frequent feedback enhances complex motor skill learning. *Journal of Motor Behavior, 30*(2), 180-192. doi:10.1080/00222899809601335

Yoshida, T., Milgrom, P., & Coldwell, S. (2002). How do U.S and Canadian dental schools teach interpersonal communication skills? *Journal of Dental Education, 66*(11), 1281-1288.

Young, J. Q., van Merrienboer, J., Durning, S., & Cate, O. T. (2014). Cognitive load theory: Implications for medical education: AMEE GUIDE NO. 86. *Medical Teacher, 36*(5), 371-384.

Yule, S., Flin, R., Maran, N., Youngson, G., Mitchell, A., Rowley, D., & Paterson-Brown, S. (2008). Debriefing surgeons on non-technical skills (NOTSS). *Cognition, Technology & Work, 10*(4), 265-274. doi:10.1007/s10111-007-0085-9

Zheng, K., Fear, K., Chaffee, B. W., Zimmerman, C. R., Karls, E. M., Gatwood, J. D., Stevenson, J. G., & Pearlman, M. D. (2011). Development and validation of a survey instrument for assessing prescribers' perception of computerized drug-drug interaction alerts. *Journal of the American Medical informatics Association, 18 Suppl 1*(1), i51-61. doi:10.1136/amiajnl-2010-000053