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An evaluation case study investigating the use of haptic ultrasound training devices to help Clinical Measurement Science students conceptualise Diagnostic Ultrasound

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An evaluation case study investigating the use of haptic ultrasound training devices to help Clinical Measurement Science students conceptualise Diagnostic Ultrasound

A thesis submitted to Dublin Institute of Technology in part fulfilment of the requirements for the award of Masters (M.A.) in Higher Education

by

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This candidate confirms that the work submitted is her own and that appropriate credit has been made to the work of others

Dedicated to Andrew and Spartacus

ABSTRACT

The aim of this project was to investigate the use of a haptic ultrasound training device as a training aid to improve students' learning, competency and confidence, in the conceptually and technically challenging area of diagnostic ultrasound imaging. The research question was investigated through the use of an evaluative case study using a mixed methods approach, with each method converging to ensure triangulation. The quantitative evaluations of the Multiple Choice Questions, psychometric manipulation test and direct observation of ultrasound scanning manipulation, demonstrated improvements of 12%, 29% and 94%, respectively between pre- and post-training performance. The qualitative evaluation of students' confidence level carrying out an ultrasound examination following the training intervention indicated that the training intervention was regarded positively by the students, demonstrated by the high level of confidence reported by the students, with a mean score of 4.43 / 5. In conclusion, the use of a haptic ultrasound training device was found to improve the students' link between theory and practice, their hand-eye coordination, and allowed them to gain confidence in diagnostic ultrasound scanning.

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CHAPTER 1. Introduction

1.1 Introduction and Context

Medical education, both at undergraduate and postgraduate level, involves adults whose education and training require the integration of theory with practice and the development of key competencies for the medical environment. Thus, it is of paramount importance that medical and healthcare students develop these key competencies in an effective manner, and be capable of working in a pressurised healthcare environment with close patient interaction.

The Dublin Institute of Technology offers an Honours Clinical Measurement Science Degree 4-year Programme (DT229), which is unique within the Republic of Ireland. It is designed to provide integrated training in the area of Clinical Measurement, whereby upon completion of the programme, graduates will contribute to the effective diagnosis and treatment of patients by performing instrument-based diagnostic measurements in the areas of cardiology, neurophysiology, pulmonary function and vascular measurements. Clinical Measurement Science students are training to become medical practitioners who will work in the healthcare environment using medical technology such as diagnostic ultrasound and interacting with patients in a pressurised environment. As such, they are at the interface between technology and medicine. In order for them to be effective Clinical Measurement Science practitioners, they need to integrate theory with practice. Specifically, they need to: (1) develop their knowledge of the specific physiology, pharmacology and medical technology; (2) develop know-how in terms of the use of the medical technology; and (3) most importantly, bring this together to develop their technical and clinical competencies in their specialist area.

1.2 Context and rationale for research

In the context of Clinical Measurement Science, it is important that the curriculum is constructively aligned. An example of how this has been achieved in the programme is the constructive alignment of modules within the different programme years, where topics are revisited at increasingly advanced levels (Prideaux, 2009). Bruner (1960) explained how this was possible through the concept of the **spiral curriculum** (Bruner, 1960)**.** This involved information being structured so that complex ideas can be taught at a simplified level first, and then re-visited at more complex levels later on. This approach was been widely implemented in different medical and healthcare curriculum (Brauer et al., 2015). The approach has been widely implemented in medical and healthcare programmes in order to bring about a more integrated learning approach in the curriculum design and learning pathway. This approach achieves both horizontal and vertical integration of the material taught in the different stages of the specific programme, which results in a more relevant and meaningful student-centred curriculum (Prideaux, 2009; Brauer et al., 2015).

An example of this in the Clinical Measurement Science programme is that students learn about the physics and technology of ultrasound imaging in the 2nd Year ***Imaging*** module (PHYS2814) of their programme. Then, in the 3rd Year of their programme while on clinical placement, they use this medical technology to achieve clinical diagnosis of different patient conditions. Finally, in 4th Year the topic of ultrasound physics is revisited at a more advanced level in Semester I and put into practice in Semester II in the clinical placement and project. Therefore, it is very important that the students of this programme integrate the theory and practice of ultrasound imaging.

The use of physical simulation models and a haptic approach within the teaching environment has been used in a wide variety of medical applications, in order to incorporate a balance between theory and practice (McGaghie et al., 2010). ‘Haptic’ in this context means the sense of touch, and haptic tools involve the incorporation of such a device to replicate this sense of touch; it could also be classified as a Technology Enhanced Learning (TEL) device (San Diego et al., 2012). This approach ties in with that of an integrated learning approach which is particularly important when learning complex tasks. In particular, it has been found that when students learn complex task in an integrated manner, it is easier for them to transfer what they have learned to the reality of day-to-day work settings (Worley et al., 2000; Prideaux, 2009). In relation to Clinical Measurement Science students undertaking the ***Imaging*** module, they are learning about: (1) how the interaction of ultrasound waves and tissue can be used to form an image; (2) what assumptions are programmed into the ultrasound machine to produce this image; (3) why artefacts are produced in the ultrasound images; and (4) how the instrument controls can be used to optimise the information in the images. All of these key areas require that the students evaluate the obtained images in terms of whether they are diagnostic or whether artefacts are present, or if further image optimisation can be achieved. However, in the work setting, these students will also have to develop good hand-eye coordination and 3D psychometric manipulation skills, in order to be able to physically scan the patient using ultrasound.

Therefore, in an attempt to enhance the learning experience for students in the programme BSc (Hons) Clinical Measurement Science, a case study evaluation was carried out. This case study evaluation specifically set out to investigate if haptic ultrasound training devices would enhance the teaching and learning experience in the Clinical Measurement Science students enrolled in the ***Imaging*** module (PHYS 2814). The study was carried out during Semester I of the academic year 2016-2017.

This module was chosen as there a number of challenges associated with the effective delivery of this ***Imaging*** module (PHYS2814). Specifically, the students are only in 2nd Year and so this is a conceptually difficult topic. Furthermore, the material in this module draws on topics which are delivered in parallel (for example, physiology), thereby requiring the student to put all these topics into context with each other. Finally, the students need to be able to cognitively map all parts of this module in order to become competent in the area and in particular, need to be able to integrate theory with practice. This is particularly important as all the different aspects of the module relating to the physics and technology of diagnostic ultrasound imaging need to be linked by the student in order to become competent in ultrasound scanning, instrument optimisation and image interpretation, and thus to bring about an effective diagnosis of a patient condition using this medical technology. In the following section, the research question underpinning this project and the aim and objectives which were constructed to answer this research question are outlined.

1.3 Research Question and Aim

"What is the impact of a haptic device on the medical ultrasound learning experience of students' from 2nd Year of the programme Clinical Measurement Science programme and how do these students perceive the use of such technology as a learning aid?"

The main aim of the project was to develop a series of haptic ultrasound training devices and investigate the impact on students' learning. The role of haptic ultrasound training devices is to enhance the integration of theory and practice. Therefore, an objective of the project was to investigate the way in which the series of haptic devices could contribute to the learning of Clinical Measurement Science students in the area of diagnostic ultrasound. A secondary objective of the project was to investigate how haptic devices could improve the confidence in students and prepare them for clinical placement in their 3rd stage of the programme.

1.4 Overview of the thesis

This thesis is organised into five chapters. Chapter One provides a context to the research question. Chapter Two focuses on the literature review, which relates to and informs the design of haptic ultrasound training devices and how a training intervention could be integrated into the ***Imaging*** module (PHYS 2814) of the Clinical Measurement Science Programme. Chapter Three discusses the research design, theories and methods for this research. Chapter Four presents and discusses the findings of this case study research. Chapter Five provides the conclusion and recommendations, and offers suggestions for further research.

CHAPTER 2. Literature Review

2.1 Introduction

The aim of the case study described in this thesis was to develop a teaching intervention which could effectively integrate the theory of medical ultrasound with its practice within a medical setting. In the area of medical education, there are many professional groups searching for the most appropriate learning theory and pedagogical practice to achieve the learning outcomes of the particular programme and facilitate the development of key competencies of the students (Abela, 2009; Edgecombe et al., 2013; Kaufman, 2003; Prideaux, 2009; Qiao et al., 2014; Taylor & Hamdy, 2013). Medical education today continues to evolve in order to meet the challenges of the stakeholders and to help students to adapt to the inevitable changes within the healthcare environment (Nalliah & Idris, 2014). This creates challenges for curriculum development, which ensure that graduates from the different medical programmes become medical professionals with the requisite competencies, but who are also capable of working in a pressurised environment. Therefore, the understanding of learning theories is of paramount importance in designing and delivering modules as part of a medical programme curriculum to meet these demands of producing a medical professional with multiple competencies (Nalliah & Idris, 2014).

2.2 Adult Learners – Theory of Andragogy

In the medical education context, both at undergraduate and postgraduate level, most education involves adults. Therefore, it is logical to focus on adult learning theories to inform the design of modules, curriculum development, pedagogical practice, training interventions and assessment modes for a group of adult learners (Abela, 2009).

There are five main classes of adult learning theories, namely: instrumental learning, self-directed learning, experiential learning, perspective transformation and situated cognition. Of these, self-directed learning particularly focuses on the individual learner as the primary focus of the theory; the most well-known of these theories is *andragogy*. Despite the fact that andragogy has been a pursued learning theory since the 20th century, it did not become a prominent learning theory until the 1980's. The uptake of this approach was due to the work of Malcom Knowles who championed this theory (Knowles, 1984). Andragogy is based on five assumptions about how adults learn and their attitude towards and motivation for learning (presented in Table 2.1). Knowles further elaborated the theory of andragogy and derived seven principles of andragogy, which are presented in Table 2.2. The fundamental essence of these principles align very well to answer the challenges associated with the development of medical education programmes with curriculums which meet the needs of the relevant medical professional. In particular, the focus of how best to integrate theory with practice and thus develop key competencies aligns well with the fundamental principles of andragogy.

Table 2.1: Andragogy—five assumptions about adult learning, adapted from (Taylor & Hamdy, 2013)

i.	Adults are independent and self-directing
ii.	They have accumulated a great deal of experience, which is a rich resource for learning
iii.	They value learning that integrates with the demands of their everyday life
iv.	They are more interested in immediate, problem centred approaches than in subject centred ones
v.	They are more motivated to learn by internal drives than by external ones

Table 2.2: Andragogy—Six principles of andragogy, adapted from (Taylor & Hamdy, 2013)

i.	The need to know (Why do I need to know this?)
ii.	The learners' self-concept (I am responsible for my own decisions)
iii.	The role of the learners' experiences (I have experiences which I value, and you should respect)
iv.	Readiness to learn (I need to learn because my circumstances are changing)
v.	(Orientation to learning (Learning will help me deal with the situation in which I find myself)
vi.	Motivation (I learn because I want to)

Another learning theory which is very applicable to adult learners is the theory of Constructivism, which relates to learning as being an active process. This principle is vital to the learner taking control over the learning process, another feature which overlaps with the learning theory of andragogy. Adult learners adopt this process of constructivism when they become self-directed learners, become aware of context and appreciate the active process through experiential learning. When learners are given the opportunity to develop skills or competencies related to their profession, this brings about the development of experiential learning, which is particularly important in relation to the medical professions. This is an important aspect of skill development and clinical competency in relation to complex tasks such as surgery or ultrasound scanning. As part of this process, students construct their knowledge while actively developing these skills and competency, while also assimilating and integrating this new knowledge gained from the experiential learning with previously assimilated knowledge. This aligns with Piaget's theory of constructivism that states that the learner will reach a level of equilibrium between the old knowledge and new knowledge gained through experiential learning (Fosnot & Perry, 1996).

It is important to keep in mind that, for the integration of knowledge and practice which bring about the assimilation of the complex skills such as ultrasound scanning, knowledge cannot be passively transferred to the learner. Furthermore, when new concepts or tasks are introduced to the learner, the learner needs to have scaffolds to support their learning, which can be achieved by them being taught, coached and taken through all the steps until they are competent. An important stage or aspect of learning is the gap between the student's ability to carry out under guidance and their ability to carry out the task independently and be able to solve related problems or carry out related tasks, which is known as the Zone of Proximal Development (ZPD) (Kneebone et al., 2004). The presentation of learning material or training interventions beyond the actual development zone of learning can frustrate the learner; therefore, this is a very important factor which needs to be taken into account for the design of any training interventions.

2.3 Simulation in Medical Education

The current process of educating new medical professionals in complex tasks such as surgery or ultrasound scanning is through the use of the apprenticeship model, wherein trainees watch a number of procedures being carried out by an expert and then they carry out various levels of this task under supervision. The trainees are given graduated levels of responsibility as their training progresses, with most of the training taking place with patients. However, this approach to medical training may no longer be suitable for current Medical Training requirements, particularly in view of the increased risk of malpractice litigation, increases in patient complexity and ethical requirements to protect patients from harm (Palter & Grantcharov, 2010). An alternative to this model is to expose the trainees to simulation-based training during the early stages of training, wherein realistic clinical training opportunities are

presented to the trainee, so they may undertake a period of training in an unpressurised environment in the absence of the patient (Torkington et al., 2000).
A large body of research exists in the area of Technology Enhanced Learning (TEL) developments in higher education in the areas of virtual and haptic simulations, modelling, online learning environments, and measurement and control devices. Their impact on teaching and learning has been investigated since the late 1970s (San Diego et al., 2012). In the areas of medicine and health sciences in particular, haptic-TEL (that is, physical feedback with a computer interface) or haptic simulator devices are being introduced into different programs to augment learning and to help teach specific clinical concepts and to train students in specific manual skills. There is growing evidence of the efficacy and effectiveness of this teaching strategy and pedagogical practice (Minogue & Jones, 2006; San Diego et al., 2012).

In medicine, evaluation of training needs together with efforts to maintain patient's safety, coupled with rapid advances in technology, led many disciplines to evaluate and validate both virtual and haptic simulation technology to be used in medical education and training (McGaghie et al., 2010). In anaesthesia and in emergency medicine, simulated clinical environments and computer-controlled full body patient simulations have been used since the mid-1990s to train anaesthetists and emergency physicians on teamwork and crisis management (Weller, 2004). Evidence in general medicine and surgical training of the benefit and the effectiveness of simulation on performance quality and of skill improvement using simulation training has been found (McGaghie et al., 2010). At first, simulators were simple models of human subjects used for diagnostic purposes. Surgical practice requires significant cognitive functions and high skill level to ensure safety of patient care. Learning of complex skills such as surgical or ultrasound procedures goes through a number of phases: the first relies on the learners understanding the components of the tasks through observing the procedures; the second depends on translating knowledge of the technique into part or full performance of the practical procedure (Kleinman, 1997). Finally, after repeated practice, the learner becomes autonomous.

The quality of the training using these virtual and haptic simulators is very much linked to the quality and realism of the training device. Simulation training in medicine has witnessed major leaps in the past few years (McGaghie et al., 2010) and these devices are now being widely introduced into different programs to augment learning and to help teach specific clinical concepts and to train students in specific manual skills in the areas of medicine and health sciences (Minogue & Jones, 2006; Newble & Entwistle, 1986). McGaghie et al., carried out a critical review of simulation-based medical education between 2003-2009 and from this review they were able to identify similarities with the training programmes (McGaghie et al., 2010). Furthermore, they identified and presented "best practice" for this type of training device within a medical education programme. Twelve features were identified as meriting consideration in the design of a hpatic device for medical education. These 12 features are presented in Table 3.1, Section 3.1, in relation to how they were implemented in the case study presented in this thesis.

San Diego et al, carried out a large formative evaluation of the use of a haptic-TEL device in dentistry programmes and included in this large scale interdisciplinary study three main strands to investigate the efficacy of this teaching strategy and pedagogical practice (San Diego et al., 2012). These three strands were: (1) a technical development and evaluation of the haptic-TEL device; (2) examining the curriculum and how it could benefit from the use of a haptic-TEL device; and (3) an education evaluation of the impact of the work carried out in Strand 1 and 2.

Training using simulation technology or a simulation laboratory offers a novice trainee an opportunity to mature into a "pre-trained novice" (Gallagher et al., 2005). A pre-trained novice is an individual who has been trained using simulation to the point where many of the complex skills such as the psychomotor navigation skills and interpretation of 3D objects in 2D images required for ultrasound imaging have been automated and occupy fewer cognitive resources. This thus allows a novice trainee to focus more on higher level learning in the ultrasound scanning room, such as taking a systematic scanning approach, performing image optimisation via instrument control, and image interpretation. Furthermore, training using simulation technology provides trainees with the opportunity to engage in deliberate practice, a key aspect of andragogy philosophy. According to K.A. Ericsson, deliberate practice is the key to expertise in professional sports, music, chess and medicine (Ericsson, 2008). Deliberate practice requires (a) a task with a well-defined goal, (b) motivation to improve, (c) provision of feedback, and (d) ample opportunities for repetition and gradual refinements in performance (Ericsson, 2008). Training on haptic ultrasound simulator devices is well suited for deliberate practice since well-defined goals can be set, feedback can be provided and multiple repetitions of a task can be performed at increasing levels of difficulty. This also aligns with Kolb's scheme, wherein the learner has a concrete experience, namely the practice session with the haptic ultrasound simulator, upon which they reflect. Through their reflection they are able to formulate abstract concepts and make appropriate generalisations. They then consolidate their understanding by testing the implications of their knowledge in new situations. This then provides them with a concrete experience, and the cycle continues.

In diagnostic ultrasound, a limited number of ultrasound simulators and haptic devices have been developed over the past two decades. The main areas which have seen the development of ultrasound simulators are obstetrics / gynaecology, prostate, and more recently in ultrasound-guided prostate brachytherapy (Madsen et al., 2014; Maul et al., 2004; McGaghie et al., 2010; Minogue & Jones, 2006; Nitsche & Brost, 2013; Weller, 2004). Considering that the quality of ultrasound examinations is highly dependent on the knowledge, skill and experience of the operator due to the hands-on and real-time nature of the modality, it is perhaps surprising that there is a dearth of suitable training aides. The consequence of this is that training typically takes place on-the-job, in a busy clinical environment, by shadowing an experienced clinical measurement scientist in the area of vascular and cardiology medicine. This approach offers no tactile feedback, does not promote the acquisition of motor and eye-hand co-ordination skills, nor does it afford trainees the opportunity to master the complex ultrasound scanning technology used for vascular and cardiology imaging examinations. Furthermore, the complexity and rapid pace of development of ultrasound technology poses further challenges for the trainee to this field.

Therefore, ultrasound training for clinical measurement scientists may benefit from the incorporation of a haptic (physical) ultrasound training device as part of the ***Imaging*** module in 2nd year, which would allow the complex skills of ultrasound scanning and 3D psychometric navigation to be developed in a non-pressurised environment. Based on the recommendations of McGaghie et al., (2010), such a haptic ultrasound training device should incorporate more than simple hand-eye co-ordination training, but should also incorporate an added level of complexity in order to allow the development of further competencies such as image acquisition (that is, familiarity with the scanner's controls and manipulation of the probe to optimise the image quality) and image interpretation, including the detection of pathologies and identification of artefacts. Therefore, the main aim of the devices presented in this thesis was to investigate the role of a haptic ultrasound device for: (1) integration of ultrasound physics theory with practice; (2) development of scanning skills and 3D psychometric manipulation; (3) image optimisation; (4) image interpretation; and (5) confidence in ultrasound scanning.

CHAPTER 3. Research Design

3.1 Introduction

In order to develop best practice in the subject area of Diagnostic Ultrasound physics and technology in the context of Clinical Measurement Science, a case study methodology was developed to investigate the research question of this thesis, specially:

> *"What is the impact of a haptic device on the medical ultrasound learning experience of students from the 2nd Year of the Clinical Measurement Science programme, and how do these students perceive the use of such technology as a learning aid?"*

A case study methodology was chosen specifically to address the project's stated aim to investigate the impact of a haptic device on student learning experience and also retain a holistic real-world perspective, such as small group behaviour (Yin, 2013). The main advantage of this methodology is that it allows one to illuminate a decision or set of decisions for a given pedagogical approach in terms of why this approach was taken, how it was implemented and with what result (Yin, 2013). Furthermore, a case study methodology embraces different epistemological orientations, for example a relativist or interpretivist compared to a realist orientation. This chapter outlines the theoretical framework underpinning this study and sets out the interrelationship between the ontological position with the other key components of the research process, namely, the epistemological approach, methodology, the methods employed and the data sources investigated, presented in Figure 3.1.

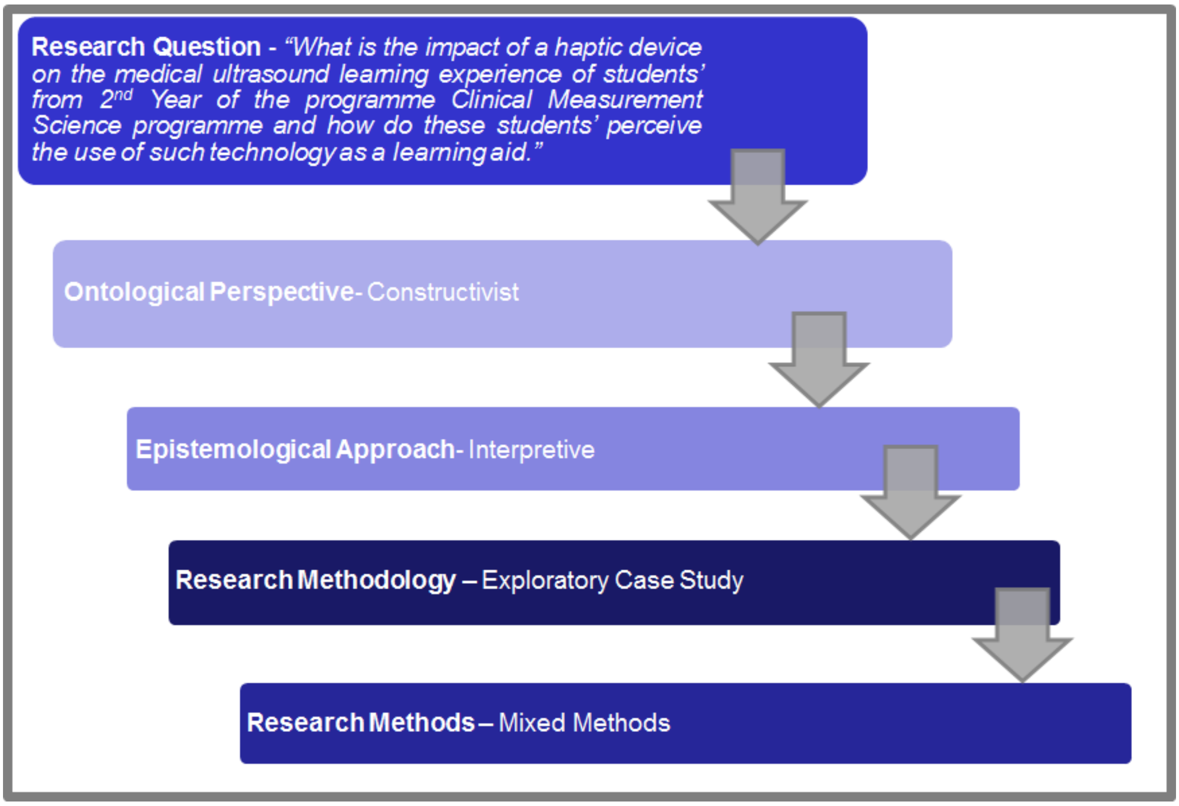

Figure 3.1 : The interrelationship between the key components of the research design

3.2 Theoretical Perspective and Approach

Determining the ontological perspective to be taken as part of a research study is a very important starting point of pedagogical research, as it describes the researcher's image of social reality upon which their theory is based. This provides the researcher's view of the nature of reality and what assumptions they make about the way in which the world works, thereby providing a framework and context for the research question to be investigated.

The nature of this study was primarily a ***naturalistic inquiry*** in order to investigate the impact of a haptic ultrasound training device on the student's learning experience within a setting which replicated the diagnostic ultrasound scanning environment wherein these students will become clinical practitioners and thus, provided context-specific research outcomes. Underpinning the naturalistic inquiry of this research was a ***constructivist ontological perspective*** which asserts that social phenomena and their meaning are continually being accomplished by social actors, in this case the Clinical Measurement Science students (Cohen, Manion, & Morrison, 2013; Grix, 2010). It is further asserted that truth and meaning are created by the subject's interactions with the world and meaning is, therefore, constructed, not discovered.

The epistemological approach which this study is influenced by is a social constructivist which assumes that *"individuals seek understanding of the world in which they live and work. They develop subjective meanings of their experiences- meanings directed toward certain objects or things"* (Creswell & Clark, 2007).
As part of the social constructivist worldview, the experiences of adult learners achieved though different learning supports which can be *"varied and multiple, leading the researcher to look for complexity of views……Often these meanings are negotiated socially and historically. In other words, they are not simply imprinted on individuals but are formed through interactions with others (hence social constructivism) and through historical and cultural norms that operate in individual lives" (Creswell & Clark, 2007).*

According to social constructivism, understanding is perceived as an interactive process between subject (Clinical Measurement Science student) and object (haptic device), in which meaning or learning experience stem from the interaction. Furthermore, this epistemological approach regards the construction of knowledge as involving both researchers and participants (Burton, Brundrett, & Jones, 2014; Grix, 2010).

Therefore, an ***interpretivist epistemological approach*** was taken in this study, because interpretivism is concerned with observing the way in which individuals construct, adjust and interpret their worlds, wherein there is a concentration on interpretation of the evidence which is used to derive meaning (Burrell & Morgan, 1979).

3.3 Methodology – Exploratory Case Study

In this investigation a case study methodology was employed, as it facilitated the study complex phenomena within their contexts, allowing exploration of the learning experience and for the research question to be investigated, while allowing the researcher take an interpretative stance (Cavaye, 1996). Furthermore, it facilitated "rich or thick" descriptions and in-depth analysis of particular instances from which one may be able to generalise more widely (Cousin, 2009; Denscombe, 2010). Therefore, for this research study this methodology was deemed most fitting, as this allowed the researcher to focus on human behaviour (Clinical Measurement Science students) and meaning (impact of haptic device), in a real-life setting to gain a deeper understanding of this central phenomena, which is the main premise of a case study (Yin, 2013). The case study methodology is common in education research since, like scientific experiments, the results are generalizable to theoretical propositions and not to the populations. In this sense, the case study, like a scientific experiment, does not represent a 'sample' and in doing case study research, the researcher's goal is to expand and generalize theories (analytic generalization's) and not to extrapolate probabilities (statistical generalization) (Yin, 2013). The ultimate goal is to a 'generalising' and not a 'particularising' analysis (Denscombe, 2010; Lipset et al., 1956).

An important aspect of case study research is its research design, of which there are five key components, which will be expanded upon in the following paragraph (Yin, 2013). Firstly, the ***research question*** needs to be suitably framed to determine the 'how and why' of the participant behavior being studied; secondly, the ***study proposition,*** each proposition directs attention to the topic that is being examined within the scope of the study; thirdly, the ***unit of analysis*** is used to bound the case, specifically the persons to be included within the group and scope of the data collection; fourthly, ***a framing of the logic which links the data to the proposition***; and finally, the ***criteria for interpreting the research findings***.

3.3.1. Haptic Device – Specification and Design

Before the series of haptic devices were developed for this project, the study design and haptic device technical specifications needed to be examined within the broader context of the learning outcomes of the students upon completion of the Clinical Measurement Science Programme and the longer-term professional requirements of the graduates of this programme. This involved consultation with the Clinical Science Measurement Clinical Tutors and through reviewing relevant literature for current international best-practice. Figure 3.2 provides an overview of how three key requirements were considered in order to identify key aspects and constraints of the case study design, and from these the haptic device technical specification was developed.

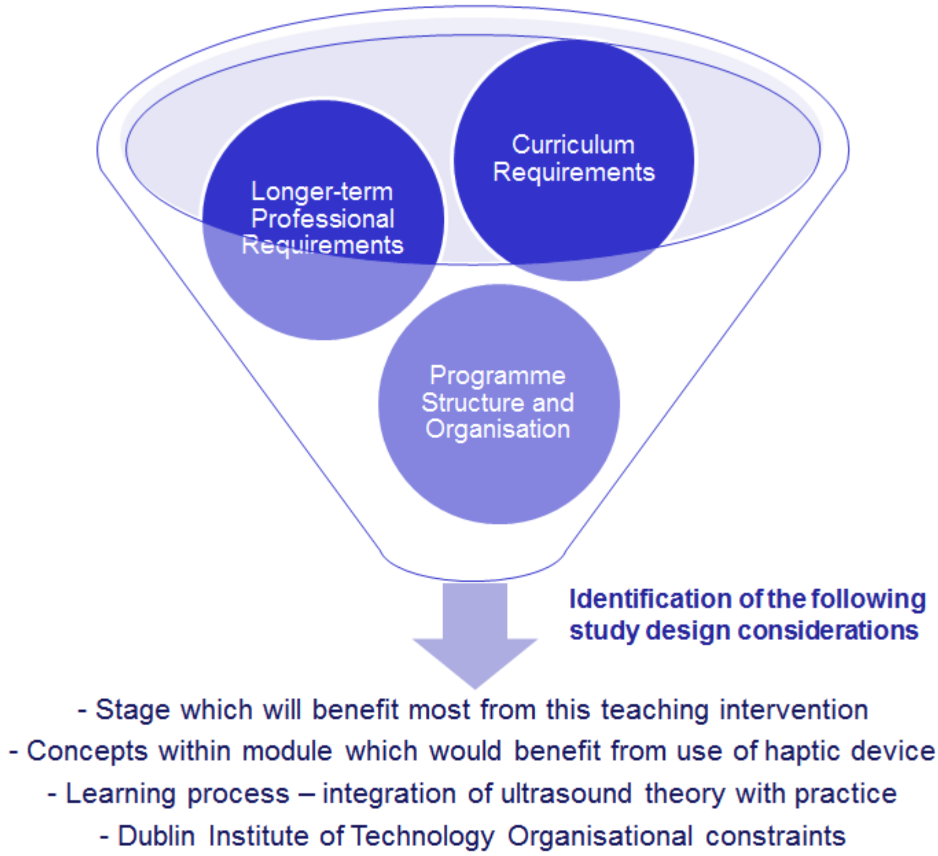

Figure 3.2: Three Key requirements for Case Study Design

As outlined in Chapter 2, the quality of the training achieved using haptic devices such as a physical ultrasound simulator is very much linked to the quality and realism of the haptic device. It was decided that the student group which would benefit most from this teaching intervention were 2nd Year students, which was determined by examining the programme curriculum. This group was specifically chosen as they are introduced to diagnostic ultrasound physics and technology in Semester I of this stage for the first time and in the subsequent stage undertake full-time clinical placement and utilise diagnostic ultrasound for clinical diagnosis in vascular and cardiac science. Through the literature review, international "**best practice**" design was identified. This **"best practice"** design was incorporated into the design of this project's haptic device by incorporating the most important 10 of haptic device design. These are outlined in Table 3.1 alongside those identified by McGaghie et al., (2010), with a description of how each feature was achieved. The informal discussions with the Clinical Measurement Science clinical tutors and practice education coordinator identified some important features for inclusion in the haptic device design in order to ensure relevance of the design for the specific learning needs of the Clinical Measurement Science students.

As part of this study, four static feature haptic devices were developed by the company CIRs Inc. (Virgina, CA), based on the design specification provided by the researcher. Each of these haptic devices had the external shape of a breast, which is considered the most difficult anatomy to image with ultrasound due to its symmetrical shape. The haptic device was composed of a combined skin and subcutaneous fat layer, a fibroglandular layer and a retro-mammary fat layer. Randomly embedded within the fibroglandular layer were 12 lesions of different echogenicity, representing the main features observed in an ultrasound examination, namely: four anechoic lesions, four hyperechoic lesions and four hypoechoic lesions. Figure 3.3(a) shows a photograph of the four haptic devices and Figure 3.3(b) shows an ultrasound image of one of the devices, with the main layers identified. In order to help the students integrate the more complex Doppler ultrasound theory and practice, a simplistic flow simulation device (Mini-Doppler Gammex RMI) was used as a learning aid in the study, Figure 3.4(a) shows a photograph of the flow simulation device and Figure 3.4(b) shows a duplex ultrasound image, with the vessel and blood velocity spectrum identified. This device contained two vessels, at 90 ° and 30 ° to the scanning surface, through which a blood analogue was pumped and the range of flow rates which replicate blood flow within the body.

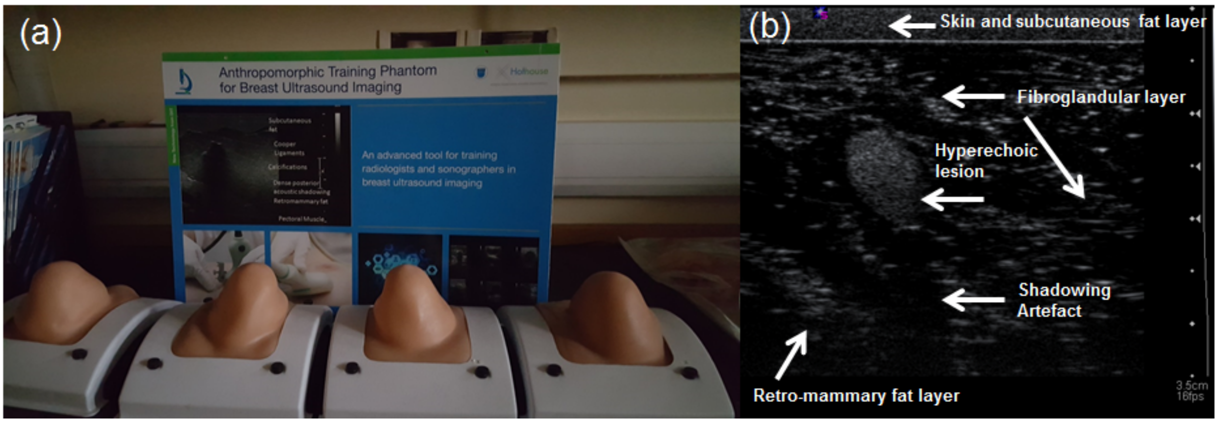

Figure 3.3(a) photograph of the four haptic devices and (b) ultrasound image from within one of the haptic devices, with the main layers identified

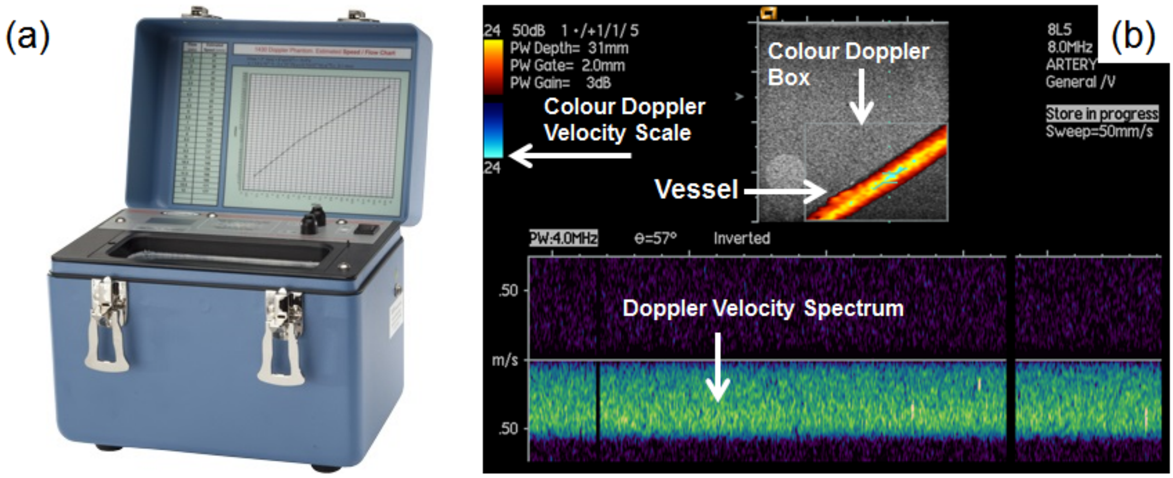

Figure 3.4(a) photograph of the flow simulation device and (b) duplex ultrasound image, with the vessel and blood velocity spectrum, each identified.

Table 3.1: Medical simulation evaluation study design features and best practices and aspects which will be investigated in the evaluation study (William C. McGaghie et al., 2010; San Diego et al., 2012)

Simulation evaluation study design features	Well-established knowledge, 'best practices'	Current Evaluation
Feedback	Essential role in Simulation Based Medical Education (SBME)	Formative Feedback was provided during the workshop sessions - the purpose of this feedback was to close the performance gap through targeted instruction about principles and skills relevant to performance, thereby promoting effective learning. (Rudolph, Simon, Raemer, & Eppich, 2008).
Deliberate practice	Essential role in SBME Learner-centred	Deliberate practice is a very important in SBME and is very demanding of the learner, epitomising the main features of student-centred learning as it requires, student motivation, engagement, repetitive practice, students to reflect on their learning experiences and commitment to the process of learning (McGaghie, Siddall, Mazmanian, & Myers, 2009; William C. McGaghie et al., 2010).
Curriculum integration	Integrate with other learning events Focus on educational objectives SBME complements clinical education	Through interviews with the Clinical tutors and the practice education coordinator, the best mix of theory and practice based learning was established as well as and how to integrate this as SBME into the Clinical Measurement Science Programme curriculum (William C. McGaghie et al., 2010; San Diego et al., 2012).
Outcome measurement	Reliable data - valid actions: research inferences Methods: observer ratings, student responses, evaluation assessment using the haptic training device	Direct observation notes of the student performance were made by a single observer to improve the reliability (researcher). Student Learning Evaluation using MCQs. 3D psychometric assessment through correct lesion detection of the range of lesions embedded with the haptic device. Survey of student experience with the haptic training device (William C. McGaghie et al., 2010; San Diego et al., 2012).
Simulation fidelity	Goals–tools match Attention to learning context	2nd Year students so the level of complexity of the device will be low to medium Haptic device had an irregular external morphology, was symmetrical and contained - different tissue layers and embedded lesions representing important features identified by the clinical tutors and practice education coordinator.(William C. McGaghie et al., 2010; San Diego et al., 2012).
Skill acquisition and maintenance	Procedural, professional, cognitive and group skills Maintenance versus decay	This task will be linked with curriculum integration (William C. McGaghie et al., 2010; San Diego et al., 2012).

Mastery learning	Rigorous approach to competency-based education	This task will be linked with curriculum integration (William C. McGaghie et al., 2010; San Diego et al., 2012).
Transfer to practice	This is the highest level of Kirkpatrick hierarchy where a stretch measurement endpoint from simulation lab to hospital or clinic is evaluated	**This will not be evaluated as part of this study, as this research is bound by a specific module in Stage 2.**
Team training	Patient care [can be] a 'team sport' Health care team training principles are evidence-based	**This will not be evaluated as part of this study, as this research is bound by a specific module in Stage 2.**
High-stakes testing	Research advances drive new test applications Highly reliable data - valid decisions	As the outcomes of this case study are being prepared as a MA thesis, recommendations for further practice based on the research findings will be made and submitted for publication in a peer-reviewed journal.
Instructor training	Effective SBME is not easy or intuitive	In this study I will be the instructor and so will not require training in the use of the haptic training device as I have used these devices extensively as part of my teaching practice.
Educational and professional context	Context authenticity is critical for SBME teaching and evaluation	This task will be linked with curriculum integration so that there is appropriate reinforcement of SBME outcomes in professional contexts (William C. McGaghie et al., 2010; San Diego et al., 2012).

3.3.2. Participants – Clinical Measurement Science Student Cohort

This study focused on the ***Imaging*** module (PHYS 2814) within 2nd Year of theClinical Measurement Science Level 8 Degree programme (DT229). This student cohort was selcted for the study following consultation with the clinical tutors and the practice education coordinator, and following the application of the 12 haptic device training approach to this study. From this analysis, it became clear that the most appropriate time for this training intervention was in 2nd Year of the Clinical Measurement Science programme, when the students are first introduced to the topic of diagnostic ultrasound through the ***Imaging*** module (PHYS 2814). The importance of this module in the learning goals of this programme is highlighted by the fact that the module is compulsory. Furthermore, the module design is such that it covers a range of topics which are interlinked to bring about an effective diagnosis for the patient using ultrasound imaging and so requires the student to develop a link or cognitive mapping of the topics covered (Appendix A).

This module runs annually in semester I from early September until early December and is delivered over 12 weeks with 2 hours of class-contact each week. This study focuses on the the 32 students enrolled in this module during Semester I of the Academic Year 2016-2017 and took place over 4 individual 3 hour sessions in which groups of 8 students participated in each session. There was a 25/75 %, male / female split within the student cohort studied.

3.3.3 Ethical Considerations

Research ethics approval was granted by the Dublin Institute of Technology Research Ethics Committee (REC) for this study, Ethical Clearance REF:14 -77 (Appendix B).

The sample selection was purposeful and all students enrolled in the ***Imaging*** Module (PHYS 2814) of 2nd Year of the Clinical Measurement Science Programme were invited to take part in this research study. There was a power balance between the researcher and the students as the researcher was the lecturer of this module. In order to ensure that the students did not feel pressurised to take part in this study, the study took place outside of the routine lecture slot times, and furthermore the students had to opt-in to the study rather than opt-out of it. The results from this study were not included nor did they affect the students' module grade, and this was clearly communicated to the students before enrolment onto the study. Furthermore, the students were verbally informed about the study and were provided with participant information sheets approximately one month prior to the study starting (Appendix C). The information sheet highlighted to participants what the study was about, how data would be collected, presented and secured, their rights and procedures, and the researcher's contact details for any questions they may have. Informed consent was requested at each workshop data gathering point to ensure that participants were happy for information to be analysed and disseminated. All participants were over 18 years of age and gave their informed consent to participate in the study (Appendix C). Each participant was given a study number which was used for all data collection purposes in order to pseudo-anonymise the participant data. The index file with the student name and study number was password protected and stored securely on an encrypted hard-drive. The hard copies of the student MCQ tests, questionnaires and observation notes were coded with the participants study number and securely stored in a locked filing cabinet in the researcher's office, which was also locked.

3.4 Research Methods

3.4.1. Overview

The research methods are the actual techniques and procedures used to collect and analyse the data in order to answer the primary research question; as such, they should be capable of answering the research question under investigation (Grix, 2010). A major advantage of case study methodology is that the researcher can avail of a number of method types to collect the data and can embrace different epistemological orientations (Grix, 2010). The research methods utilised to collect the data in this project compromised of a mixed method approach. The rationale for using a mixed methods approach was that case study inquiry requires multiple sources of evidence with data converging in a ***triangulation fashion*** in order to improve the validity of the research findings and to establish a chain of evidence (Yin, 2013). Through mixed methods research, the researcher is forced to share the same research question to collect complementary data and to conduct counterpart analysis, thereby facilitating more complicated research questions to be addressed in the study (Yin, 2013). In summary, mixed methods research provides "a richer and stronger array of evidence than can be accomplished by any single method" (Yin, 2013). Cohen et al. (2013) defined triangulation as an "attempt to map out, or explain more fully, the richness and complexity of human behaviour by studying it from more than one standpoint" (Cohen et al., 2013). Figure 3.5 provides a visualisation of the mixed method approach which was used in this case study research and how each method converged to ensure '***triangulation'*** of collected data, thereby increasing the reliability of the research findings of the case study undertaken.

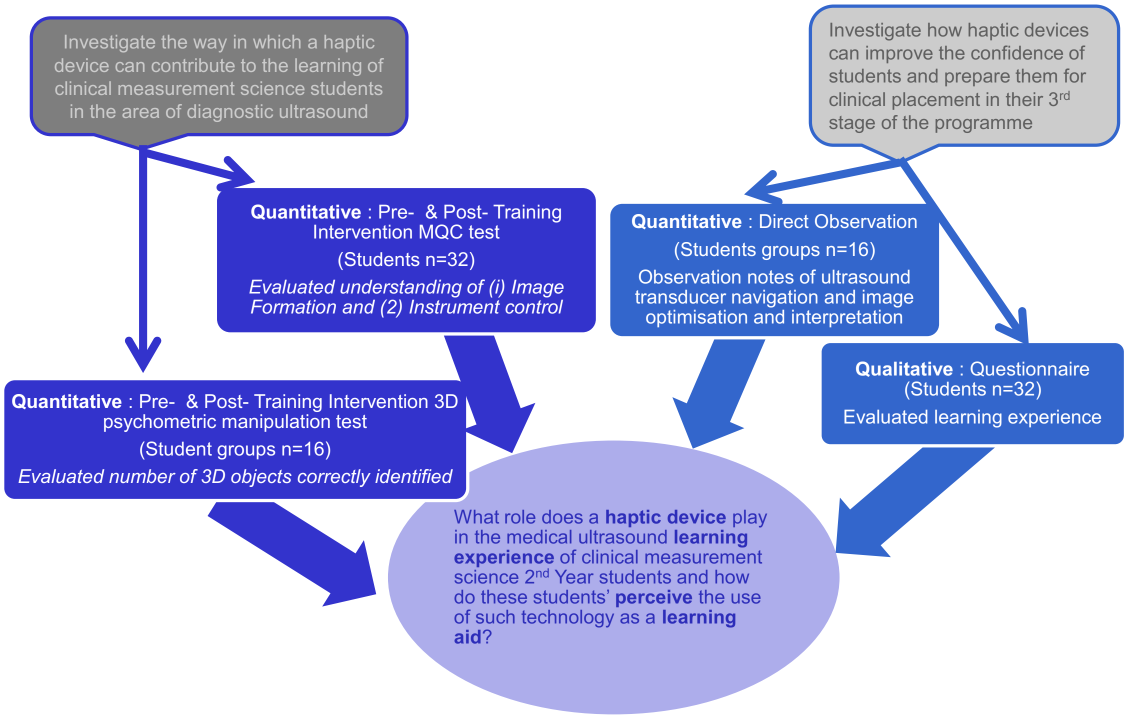

Figure 3.5: Schematic of Mixed Method approach taken in the case study, it can be seen from the arrows that all methods converge to answer the primary research question.

3.4.2. Quantitative Evaluation: Multiple Choice Question (MCQ) Test

The researcher used a pre- and post-training intervention MCQ test to determine the extent of learning before and after the training intervention involving the haptic device learning aid. The MCQ test was administered to 32 students and a comparison of their performance before and after the training intervention was made; a copy of the MCQ test is provided in Appendix D. This MCQ test was specifically designed to evaluate two different aspects of learning: (1) the students' understanding of image formation, and (2) the students' understanding of the role of different ultrasound instrument controls. This represented Level 2 on the Kirkpatrick Evaluation Tool.

3.4.3. Quantitative Evaluation: 3D Psychometric Manipulation Test

The researcher used a pre- and post-training intervention 3D psychometric manipulation test to determine the integration of ultrasound theory into practice, which was evaluated through the identification of the 12 lesions with the haptic device. This test required the student to integrate hand-eye coordination and interpret and mentally manipulate the 2D ultrasound images of the 3D lesions within the haptic device in order to correctly identify them and find the 12 different lesions embedded within the haptic device. The 3D psychometric manipulation test was administered to 16 group pairs to the 32 students and a comparison of each groups (n=16) performance before and after the training intervention was made. This 3D psychometric manipulation test was specifically designed to evaluate the students' understanding of image formation and their ability to identify different regions of echogenicity as lesions or tissue layers; this represented Level 2 on the Kirkpatrick Evaluation Tool.

3.4.4. Quantitative Evaluation: Direct Observation of student group interaction with haptic device

The researcher used a pre- and post-training intervention direct observation in order to determine whether the haptic device could help prepare the students for their clinical placement through the development of their transducer navigation skills as well as their image optimisation and interpretation skills. In order to determine this, the researcher directly observed and made notes of the students' ability to navigate around the haptic device and correctly optimise and interpret the relevant ultrasound images; a copy of the observation note template is provided in Appendix E. These direct observations were made over three 10 minute slots for each of the 16 individual group pairs in order to monitor each groups' (n=16) performance before and after the training intervention was made. This was achieved through four separate three-hour workshop sessions which accommodated four groups of two at each session. This number per workshop was chosen for two reasons: firstly, the researcher could not reliability observe more than four groups per session, and secondly, there were only four haptic devices available for the study. Finally, the use of only one observer for all students provided the research findings with increased reliability and validity. Figure 3.6 provides a flow chart of the process employed during the direct observation evaluation of each student group during the four workshop sessions.

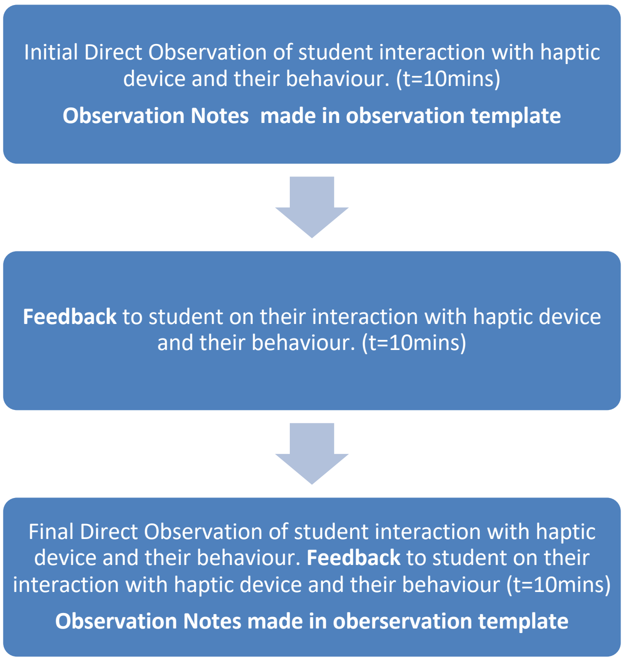

Figure 3.6 : Flow chart of the process employed during the direct observation evaluation of each student group during the workshop session

3.4.5. Qualitative Evaluation: Questionnaire of the students' learning experience with the haptic device

The researcher used a post-training intervention questionnaire to determine how the students' perceived the use of the haptic device in terms of improving their integration of ultrasound theory into practice and whether they felt more confident operating an ultrasound system. The post-training intervention questionnaire was administered to the 32 students and their response was recorded using a five-point Likert scale (Appendix F). This questionnaire was specifically designed to evaluate the students' reaction to the haptic device and the training intervention and how they felt about the learning experience; this represented Level 1 on the Kirkpatrick Evaluation Tool and is commonly known as a "Happy Sheet".

3.5 Delimitations

The use of case study research in education has a boundary in either the programme, the institution, a module or particular innovation in education (Cousin, 2005). This study was limited as it only allowed for investigation of the research question within one Clinical Measurement Science module within 2nd Year of the Clinical Measurement Science Programme. The main delimitations associated with this case study design were the following:

i. A qualitative evaluation of trainee performance pre- and post-training intervention, using the haptic ultrasound training device, was performed using direct observation notes but the reliability of this was improved through the use of one observer.
ii. Observer effect – the presence of the researcher may have resulted in the students behaving differently.
iii. There was no comparison between learning with and without haptic device, which could only have been evaluated if only half of the student cohort were given the opportunity to undertake the training intervention. However, the use of the pre- and post-training intervention MCQ test and the 3D psychometric manipulation test provided an insight into the learning achieved by the students using this haptic device.

iv. When using a haptic device with a group who have never carried out ultrasound scanning previously, there is a risk of cognitive load due to the haptic device itself. In order to mitigate this risk, a relatively simplistic haptic device was developed which would not require much orientation and training for the student.

These delimitations mean that the study findings and recommendations must be interpreted cautiously and that care must be taken not to generalise the results too widely.

3.6 Summary

This chapter described the use of the case study methodology for this research study. This chapter also described the ethical considerations, the data collection methods and the limitations of this research study. The following chapter will analyse and discuss the data gathered and the findings that emerged.

CHAPTER 4. Data Analysis, Presentation and Discussion of Findings

4.1 Introduction

This chapter presents and discusses the findings relating to the aim of this project which was to develop a haptic ultrasound training device and investigate its impact on students' learning. This aim was achieved by carrying out the main objectives. The first objective was the development of a series of haptic devices, the main details of which were discussed in Chapter 3 section 3.3.2. The second objective was to investigate the way in which the series of haptic devices contributed to the learning of the Clinical Measurement Science students' in the area of diagnostic ultrasound; this was achieved through the quantitative MCQ and 3D Psychometric Manipulation tests and the qualitative direction observations. The third objective was to investigate whether the series of haptic devices impacted the students' confidence in ultrasound scanning; this was achieved through a post-training intervention questionnaire. The use of triangulation in this case study provided the researcher with convergence and correspondence of the data from the different quantitative and qualitative methods, to answer the study's primary research question. The study hypothesis was tested by comparing the level of knowledge, skills and confidence achieved by the participants both pre- and post-training intervention. Continuous variables were compared with the Student's t-test, and a p value of < 0.05 was considered significant. The results and findings from each research method, along with a discussion of the relevance of these results, is provided in the following sections.

4.2 Quantitative Evaluation - Multiple Choice Question (MCQ) Test

A pre- and post-training intervention MCQ test was used to determine the extent of learning before and after the training intervention involving the haptic ultrasound training device. The MCQ test was administered to 32 students and the results for the MCQ test pre- and post-training intervention for all the study participants are presented in Figure 4.1. It was found that on average the MCQ test scores post-training were higher than the MCQ test scores pre-training (53% ± 17%, vs 41% ± 21%, $p < 0.01$). In terms of the impact of the training intervention, 53% of the students MCQ test scores improved, 28% had no change in their score while 19% of the students performed worse in the post-training MCQ test (Figure 4.2). This latter finding may be indicative of some of the students experiencing cognitive load due to the additional learning associated with using the haptic device, navigation of the ultrasound transducer and also optimising the ultrasound system. However, the haptic ultrasound training device was designed so that the cognitive load would be minimal. Since the MCQ score results relating to the instrument control questions improved, it may have been the design of the workshop which caused this cognitive load on the participants rather than the training device.

There are two main types of cognitive load, intrinsic and extraneous, which need to be considered to determine the main source of cognitive load experienced by the students (Sweller, 1994). The workshop provided the participants with a single 3 hour training workshop during which time they had two assessments (pre- and post-training intervention) and the training period, and this may have caused cognitive load in some of the participants as it has been found the working memory capacity of students limits their performance in complex tasks such as problem solving (Danili & Reid, 2004; Sweller, 1988, 1994). The working memory limits the amount of information a person can process and is an important aspect of cognitive load. In a particular teaching context, the working memory load experienced by learners is based on both intrinsic load and the teaching methods employed (Sweller, 1994). Therefore, it is particularly important in medical learning to consider the volume of information presented to the learner as this can cause high cognitive load because of the required level of interactivity of the elements being taught as well as the clinical reasoning required. This is the main reason why it is important to have an integrated programme curriculum with material delivered in digestible chunks, with interconnectivity between subjects explicitly identified and pedagogical practices which facilitate constructive learning. Learning processes could be affected when the cognitive load exceeds the limit of Working Memory Capacity (Sweller, 1994).

The MCQ test was designed to evaluate two different aspects of learning: (1) the students' understanding of image formation, and (2) the students' understanding of the role of different ultrasound instrument controls. The main area of improvement in the MCQ test scores was due to the students' improvement in their cognitive knowledge of instrument control theory rather than their understanding of image formation. This finding was also borne out in the images that the students' captured for the identified lesions within the haptic device, which demonstrated improved image optimisation (Figure 4.3). This ability to optimise the images is related to their knowledge of the role of the different ultrasound instrument controls.

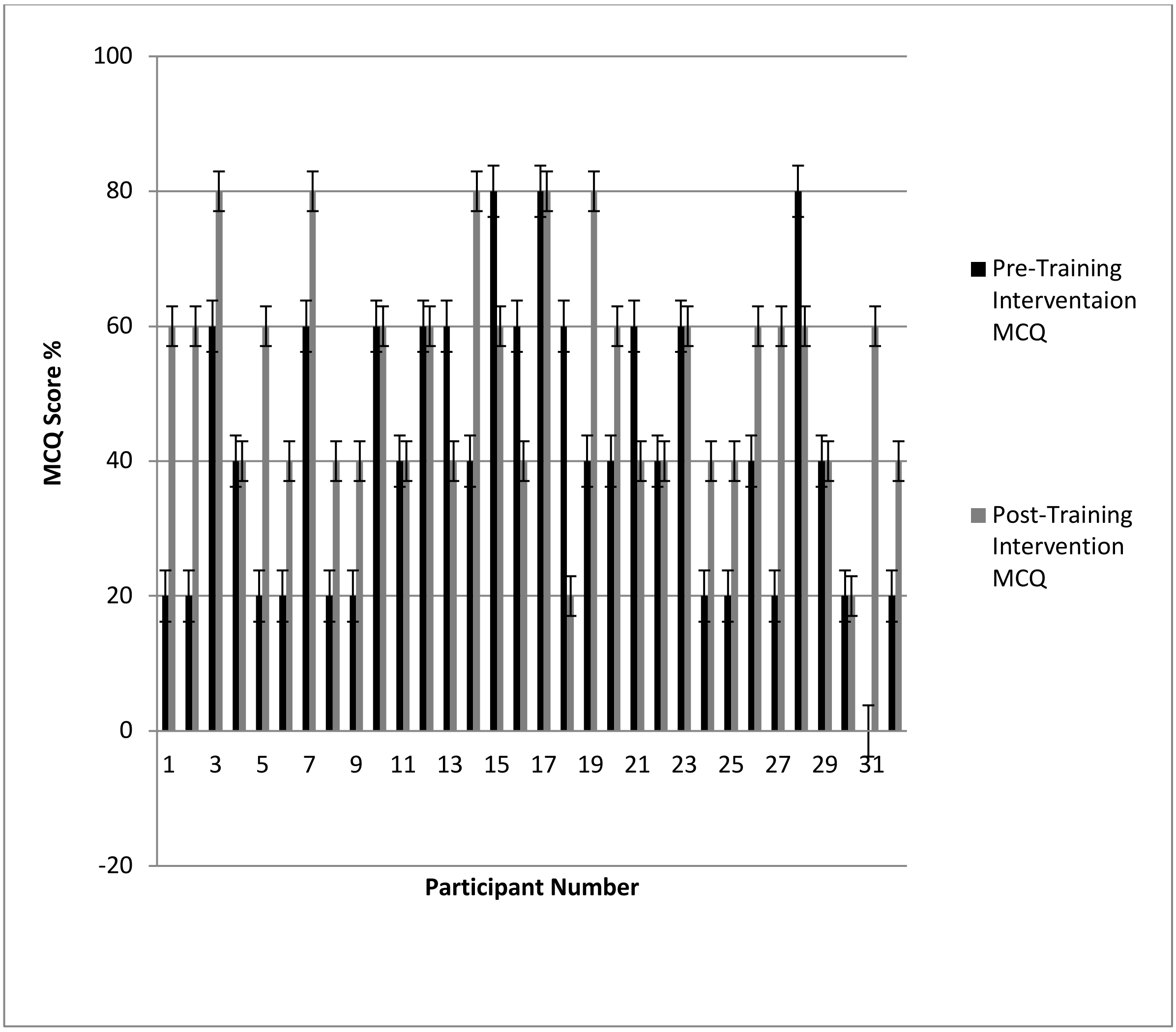

Figure 4.1 : MCQ test pre- and post-training intervention results for the 32 study participants

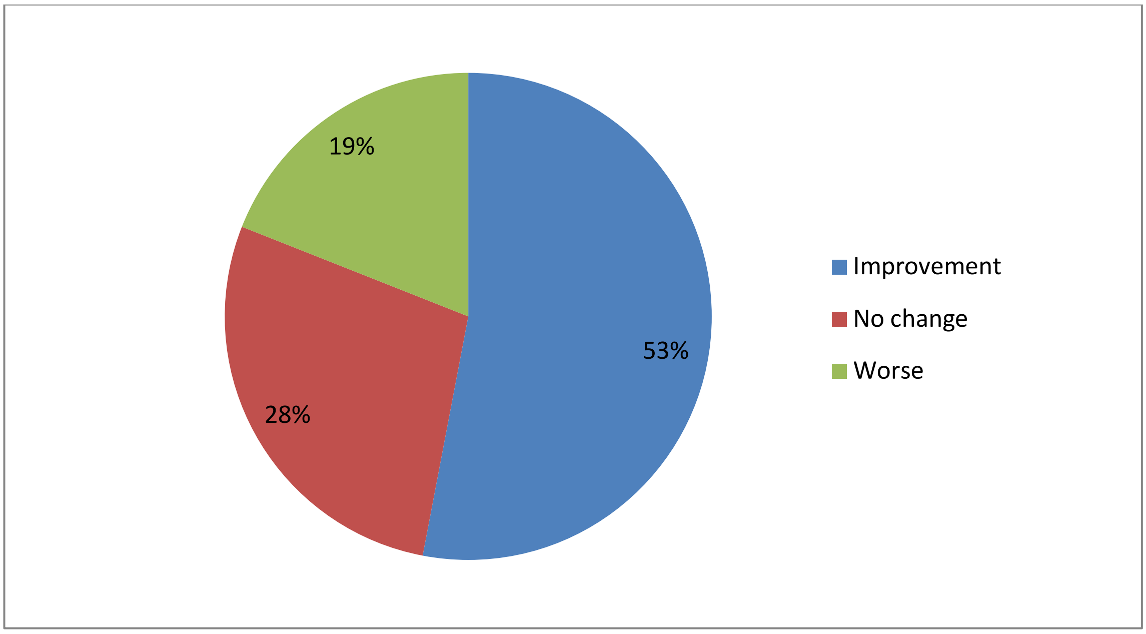

Figure 4.2: Change in MCQ test results following the training intervention

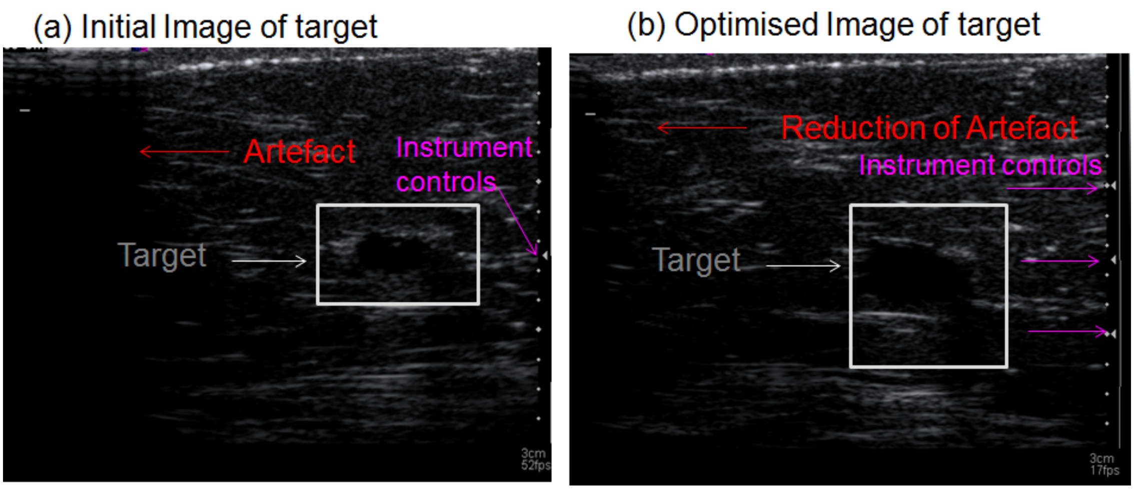

Figure 4.3: Ultrasound Images of the embedded lesion within the haptic ultrasound training device acquired by one of the student groups (a) initial image of target pre-training intervention demonstrating significant artefact and poorly optimised image of the lesion, and (b) image post-training intervention demonstrating reduction in artefact and good optimisation of the lesion

4.3 Quantitative Evaluation - 3D Psychometric Manipulation Test

A pre- and post-training intervention 3D psychometric manipulation test was used to determine the integration of ultrasound theory into practice, which was evaluated through a practical assessment. In this assessment the participants were required to locate and identify the 12 lesions which were embedded within the haptic device, which were either anechoic (n=4), hyperechoic (n=4) or hypoechoic (n=4). This test required the student to integrate hand-eye coordination and interpret and mentally manipulate the 2D ultrasound images of the 3D lesions within the haptic device, in order to correctly identify them and find the 12 different lesions embedded within the haptic device. The 3D psychometric manipulation test was administered as 16 group pairs to the 32 students and a comparison of each groups' (n=16) performance pre- and post-training intervention was made; the results for all the study participants are presented in Figure 4.4. The results of the participant groups on the practical assessment significantly improved with the average number of lesions detected by each group increasing post-training intervention (61% ± 12%) compared to pre-training intervention (32% ± 11%), with a $p < 0.0001$. The highest lesion detection score achieved post-training by the participants was 75%, which indicates that even the best group of students did not find all of the lesions within the timeframe of the training workshop. However, it does demonstrate that the participants benefited from the training intervention and improved their 3D psychometric manipulation skills by undertaking a period of deliberate practice using the haptic ultrasound training device. The main aim of this research study was to determine whether the 2nd Year Clinical Measurement Science students would benefit from a training intervention using a haptic device and the results from the psychometric manipulation test are indicative that the student participants have benefited from this training intervention evidenced by the average improvement in the number of lesions detected by each group post-training intervention. The current training practice in Clinical

Measurement Science and the majority of medical programmes is that the student or trainee undertakes an apprenticeship teaching method which as discussed in chapter 2 does not provide the learner with an opportunity to learn through deliberate self-directed practice in a non-pressurised environment as is provided through the use of a haptic ultrasound training device.

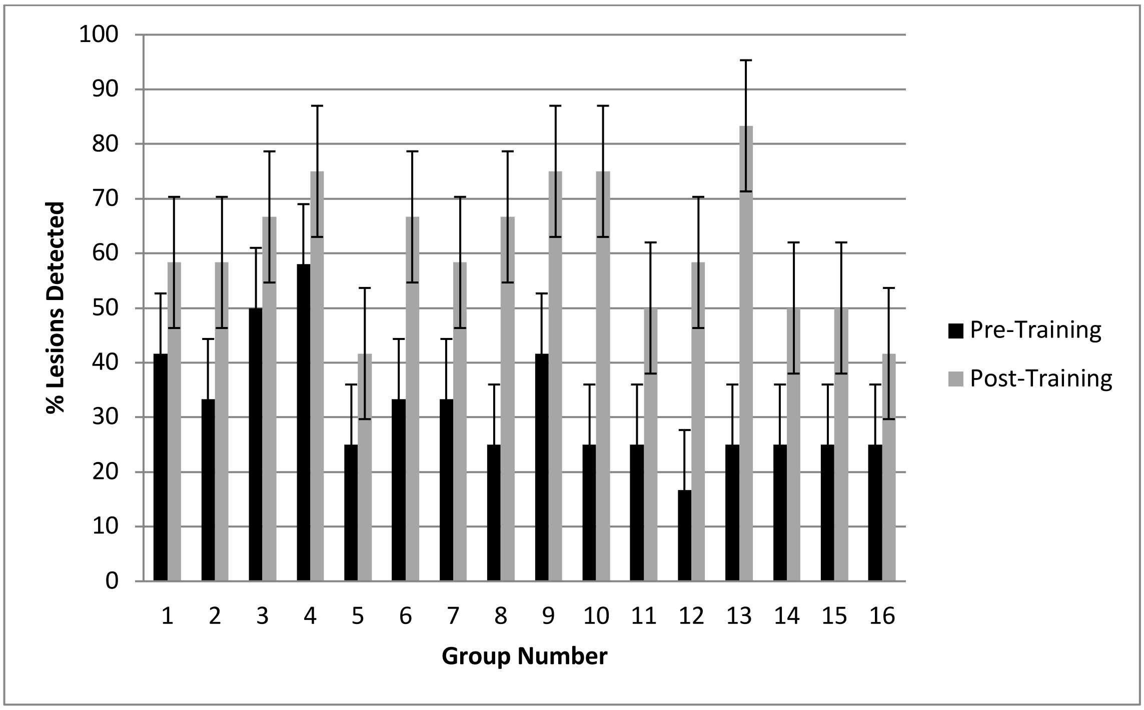

Figure 4.4: Comparison of results from 3D psychometric manipulation test pre- and post-training intervention for the 16 student groups

The improvement in both the knowledge and 3D psychometric manipulation skills was found to be statistically significant for pre- and post-training intervention. The training workshop intervention was carried out over a block of time, 3 hours, due to the constraints of the requirement to hold the workshop outside of class time and the students' timetable. There have been studies which have investigated the optimum set-up and practice time for a learning intervention such as a haptic ultrasound training device and they have compared two approaches, massed (all at one time) versus distributed (spaced across a number of sessions) for optimising the learning of motor skills. In a meta-analysis by Donovan & Radosevich (1999) of 63 studies, the effect of the training intervention over a distributed practice schedule were found to diminish with increased task complexity and increasing time interval between practice sessions. The ultrasound scanning skills which were being taught and developed through the training intervention described in this project were complex, and so it would be expected that the approach of a massed training session would have provide the best results. However, given the results of the MCQ test in terms of 28% with no change and 19% of the students with worse results, it is possible that the teaching methods employed, namely massed approach, was a source of extrinsic cognitive load. Therefore, it may have been more optimum to run distributed workshops with well-defined tasks and concentrated feedback on one aspect of performance related to a well-defined task in multiple workshop sessions.

This finding was also confirmed through the erratic ultrasound scanning approach exhibited by a number of the students during the qualitative evaluation of direct observation; the direct observation phase of this investigation will be discussed in the next section. Similar observations were made by Reznick and MacRae, (2006) in terms of the acquisition of technical skills in surgery which is considered to be the first cognitive stage in motor learning theory (Reznick & MacRae, 2006). During this stage, the learner begins to intellectualize the technical procedure at hand, their performance is erratic and the procedure is carried out in distinct quantised steps. However, with continued practice and appropriate feedback, the learner will move from the cognitive to the integrative stage. In the study described in this thesis, the learners did not get to carry out extended practice beyond the 3-hour workshop and so may not have moved to the integrative stage, where they begin to translate the knowledge acquired in the cognitive stage into appropriate motor behaviours. For example, the learners did not demonstrate good fluidity in terms of the execution of their ultrasound scanning examination. With on-going deliberate practice, the learner may have transitioned from the integrative to the autonomous stage, where motor performance becomes more smooth and automated. At this stage the learner would no longer need to think about how to execute a particular procedure and could instead concentrate on other aspects of patient care.

4.4 Quantitative Evaluation - Direct Observation of student group interaction with haptic device

A pre- and post-training intervention direct observation evaluation was used to determine whether the haptic device could help prepare the students for their clinical placement through the development of their transducer navigation skills as well as their image optimisation and interpretation skills. To evaluate this aspect of the study, notes were made of the students' ability to navigate around the haptic device, correctly implement image optimisation and interpret the relevant ultrasound images, during direct observation; a copy of the observation note template is provided in Appendix E. These direct observations were made over three 10 minute slots for each of the four individual group pairs within each workshop. In order to ensure reliability and consistency between each direct observation of all 16 student groups across the four workshop sessions, a direct observation template was used to monitor the most important student interactions with the haptic device and to record their behaviour. Three different aspects of behaviour were recorded pre- and post-training intervention: technical knowledge, technical performance and tissue identification competency; these are presented in Table 4.1. Furthermore, during the workshop, limited feedback was provided to the participants in part due to the time constraints of the tasks required to complete during the workshop, but also due to the findings from previous medical education studies investigating the use of simulation workshop as training interventions (Xeroulis et al., 2007). Rather, the main feedback was provided following the post-training assessment to provide each participant with key points for improvement. In particular, the value and impact of different types of feedback on trainee performance in these studies was taken into consideration given the importance of feedback in any educational intervention (Issenberg et al., 2005). Through feedback, the trainee was provided with information about the accuracy of their actions; specifically, they are reinforced when correct and dissuaded when incorrect. It has been found in previous studies involving training interventions that this approach to providing feedback provides an important source of motivation to the trainee (Xeroulis et al., 2007). There are two major types of feedback: intrinsic and extrinsic (Magill, 2004). Intrinsic feedback relies on performance-related information that is available directly to the sensory system of the performer, such as visual or auditory perceptions during the performance of a task and is linked to the realism of the simulation device. Extrinsic feedback relies on performance related information that is provided by an external source, such as the trainer, mentor or lecturer. The aim of the extrinsic feedback is to augment the intrinsic feedback (Magill, 2004). The extrinsic feedback can be administered during the training intervention concurrently or as a summary following the training session. The effects of concurrent and summary feedback on technical skill acquisition in medical students have been compared in a number of medical training applications, basic surgical skills, endoscopy and laparoscopic suturing skills. In these studies, the effect of the two types of feedback was compared by randomly allocating the students into 3 groups which received no feedback, concurrent feedback and summary feedback. It was found in each of these studies that the two groups who received feedback (concurrent and summary) performed better than the group which received no feedback (Magill, 2004). Furthermore, the group which received summary feedback performed better than the group which received concurrent feedback. In an investigation of basic surgical training, the authors concluded, “summary feedback is more effective that concurrent feedback in teaching basic technical skills to medical students” (Xeroulis et al., 2007).

In an investigation into endoscopic suturing skills found that summary feedback was more effective in teaching basic endoscopic procedures than concurrent feedback (Walsh, Ling, Wang, & Carnahan, 2009). Another investigation examining the effects of feedback on the acquisition of laparoscopic suturing skills in novice medical students found that limited summary feedback appeared to be superior to intense summary feedback. Furthermore, intense feedback during early stages of skill acquisition was hypothesized to hinder learning (Nitsch, 2012). The beneficial effects of summary feedback can be explained using the Guidance Hypothesis proposed by (Winstein & Schmidt, 1990). In this hypothesis, feedback is expected to guide the learner toward the intended goal by providing information on error correction and by keeping the learner motivated and interested. If feedback is too frequent, as is the case with concurrent feedback, the learner may develop a dependency on this type of feedback, and its presence may become essential for performance. When concurrent feedback is removed, as in the case with retention testing, the learner's performance suffers. The guidance hypothesis suggests that concurrent feedback may direct a learner's attention away from the critical intrinsic feedback, whereas summary feedback may allow a trainee to process and consolidate intrinsic feedback during the task and receive extrinsic feedback at the end of the task.

Given these findings from previous investigations and the evidence of potential cognitive load to the participants found in this case study, an alternative approach of providing the feedback following the workshop session in written format may have provided more optimum outcome from the training intervention. In particular, this type of feedback would have provided the students with self-reflection points, on the individual aspects of their performance which could have been used to direct their self-directed learning pathway and deliberate practice.

Table 4.1: Rate for correct technical performance and tissue type identification

		Student Group (n=16) Pre-training Intervention Rate (%)	Student Group (n=16) Post-training Intervention Rate (%)
Technical Knowledge			
i.	*Correct selection of transducer*	25	100
ii.	*Correct selection of frequency*	0	100
iii.	*Correct selection of clinical application pre-set*	32	100
Technical Performance - Correct use of ultrasound system controls for image optimisation			
i.	*Time Gain Compensation*	0	100
ii.	*Overall Gain*	6	100
iii.	*Acoustic Output Power*	0	100
iv.	*Focal Zones*	0	100
v.	*Depth of Field of View*	13	100
Tissue identification competency			
i.	*Specular Reflector*	50	100
ii.	*Stochastic Reflector*	7	100
iii.	*Hyperechoic lesion*	75	100
iv.	*Anechoic lesion*	7	100
v.	*Hypoechoic lesion*	75	100

4.5 Qualitative Evaluation - Questionnaire of the students' learning experience with the haptic device

A post-training intervention questionnaire was used to determine how the students' perceived the use of the haptic device in terms of improving their integration of ultrasound theory into practice, and whether they felt more confident operating an ultrasound system. The post-training intervention questionnaire was administered to the 32 students and their response was recorded using a five-point Likert scale. This questionnaire was specifically designed to evaluate the students' reaction to the haptic device and the training intervention and how they felt about the learning experience; this represented Level 1 on the Kirkpatrick Evaluation Tool and is commonly known as a "Happy Sheet". The purpose of this questionnaire was to gauge the following aspects of the training intervention's impact and potentially to serve as a framework for future changes to the pedagogical approach implemented for achieving the learning outcomes and competences from this ***Imaging*** Module (PHYS2814) and the summary responses are presented in Table 4.2.

Overall, the level of confidence reported by the participants for each of the three main training aspects was > 4.43 / 5. Also, the two questions relating specifically to the training intervention scored a very high satisfaction level from the participants of > 4.87 /5, indicating that the majority of participants felt that this pedagogical approach served as a valuable training intervention for this technically and conceptually difficult subject of ultrasound physics and technology. The three questions below interrogate three main aspects of performance which were also evaluated through the MCQ test and the lesion detection assessment, namely: are the students proficient in basic skills (such as technical scanning aspects – operation of ultrasound scanner); core skills (such as image perception – integration of theory and practice); and more advanced levels of performance (such as integrating scan results with patient care).

1. Confidence in the operation of an ultrasound scanner.
2. Integration of theory and practice.
3. Confidence in carrying out an ultrasound examination for example with a patient.

The relatively high number of participants and internal consistency support the validity of the results, which makes it possible to analyze the training characteristics of whole populations to inform the design of this ultrasound ***Imaging*** module in the future. However, there are some limitations associated with using this type of questionnaire, the most significant of which is the unreliable nature of self-assessment (Ward, Gruppen, & Regehr, 2002). For example, trainees have difficulty in objectively rating their ability particularly relating to their actual ability or competence. Some trainees are not aware of their own incompetence and may be falsely confident, whereas more knowledgeable and skilled trainees may be aware of their own limitations and provide lower confidence ratings. Another limitation of the approach taken was that self-confidence was only measured immediately after the workshop; it would have been interesting to have a pre-workshop confidence self-assessment, which would have provided information about the overall confidence of the group prior to the workshop and whether the workshop had an impact on their confidence rating (Ward et al., 2002). However, it is not known whether the confidence indicated by the participants was short lived or persistent over time, and in particular whether it impacted their confidence prior to the 3rd year clinical work placement.

Table 4.2 : Descriptive statistics for questionnaire summary results for exploration of association between haptic device training intervention and students' level of confidence in performing ultrasound scans

Questions *Statements (1, strongly disagree; 5, strongly agree)*		*Mean (Standard Deviation)*
(i)	The haptic simulation device created a learning environment in which I felt comfortable.	5 (0)
(ii)	The scanning session helped me to develop my confidence in the operation of an ultrasound scanner.	4.77 (0.43)
(iii)	The scanning session helped me develop my confidence in carrying out an ultrasound examination for example with a patient.	4.43 (0.77)
(iv)	The session was effective in helping me to integrate theory and practice.	4.47 (0.78)
(v)	The training device produced a valuable training experience.	4.87 (0.35)

4.2 Summary

The main aim of the project was to develop a haptic ultrasound training device and investigate its impact on students' learning, competency and confidence - this was successfully achieved in this project.

It was found that the haptic device and training intervention benefited the participants in the following ways:

(i) Improved the link between theory and practice for ultrasound system manipulation and instrument control - by undertaking a period of deliberate practice using the haptic device and feedback;

(ii) Improved the participants' ultrasound scanning skills and improved their 3D psychometric manipulation skills – by undertaking a period of deliberate practice using the haptic device and feedback;

(iii) Improved the participants' confidence and helped prepare them for clinical placement – haptic devices presented a challenging real-life scenario without the pressure of the presence of a patient.

CHAPTER 5. Conclusions and Recommendations

5.1 SUMMARY

The main aim of the project was to develop a haptic diagnostic ultrasound training device and investigate its impact on students' learning. Therefore, the first objective of this project was to design and develop a suitable haptic ultrasound training device for use in the study. This was achieved by reviewing the different ultrasound physics modules within the Clinical Measurement Science Programme curriculum. Through this review the ***Imaging*** module (PHYS 2814) was identified as being best suited to the use of such haptic ultrasound training devices. Furthermore, the most troublesome theoretical concepts of the ***Imaging*** module, i.e. that students from previous cohorts of this programme have struggled most to link with clinical practice, where incorporated into the design of the haptic ultrasound training device. The design of the device was further refined based on the specifications highlighted by the Clinical Measurement Science tutors during focused discussions. The main considerations were that the training device would be moderately complex (have a morphological shape, contain tissue layers, produce artefacts and contain both normal tissue and pathologies), but have a moderate cognitive load in terms of the training that would be required to use the training device. All of these specifications were achieved in the final training device that the company CIRS was consulted to build and it adequately replicated the challenging clinical morphology of the breast. Using this haptic training device, it was then possible to design an evaluation case study to investigate the impact of this device on the learning, competence and confidence of the 2nd Year Clinical Measurement Science students.

It was found that the haptic ultrasound training device and training intervention benefited the participants in the following ways:

(i) Improved the link between theory and practice for ultrasound system manipulation and instrument control, as it was found that on average the MCQ test scores post-training were higher than the MCQ test scores pre-training (53% ± 17%, versus 41% ± 21%; $p < 0.01$) ;

(ii) Improved the participants' ultrasound scanning skills and improved their 3D psychometric navigation skills. This was demonstrated by the results of the participant groups on the practical assessment, which showed a significant improvement in the average number of lesions detected by each group post-training intervention (61% ± 12%) compared to pre-training intervention (32% ± 11%), with a $p < 0.0001$;

(iii) Improved the participants' confidence and helped them to better integrate theory with practice, which was demonstrated by the participant rating score of > 4.43 / 5. Furthermore, there was a significant improvement in the participants' use of the ultrasound system instrument controls post-training.

Therefore, the main advantages of the haptic ultrasound training device presented in this thesis are: (1) the morphological shape allows trainees to develop and improve their hand-eye coordination skills; (2) allows trainees to build confidence in ultrasound scanning; (3) improves the ability of inexperienced Clinical Measurement Science students to detect and correctly characterise lesions; and (4) demonstrates the effect of instrument controls.

5.2 Limitations

There are some limitations associated with this study which need to be considered when interpreting the results. The most significant limitation was the fact that the learning intervention took place over a 3 hour period in the form of a workshop, as this appeared to have caused cognitive load in some of the participants. There were two reasons for choosing this configuration for the training intervention. Firstly, it needed to take place outside of the lecture time to avoid the students feeling pressurised to take part in the training intervention, which meant that there were limited lecture slots available for the training intervention to take place in. Secondly, previous studies have found that for learning complex skills such as ultrasound scanning, and surgical and endoscopic suturing, a massed approach should be taken rather than a periodic scheduled approach (Donovan & Radosevich, 1999; Zevin, 2014). However, a significant difference between these reported studies and the current project was that the participants of these studies were more advanced in their training and had already spent time in the clinical environment, while the Clinical Measurement Science students who took part in the current study were only in 2nd year of their programme and furthermore had no direct experience of the clinical environment. Therefore, a scheduled practice approach may have provided a greater learning impact with a lower cognitive load.

The second limitation of the study design, which was also related to the cognitive load which some of the participants experienced, was that too many tasks may have been introduced and assessed during the workshop. A better approach to implementing this type of training intervention may be to direct each training session towards the acquisition of specific skills by the participants undertaking one specific task.

The third limitation was the mode of feedback provided to the participants. Feedback on all performance aspects evaluated during the workshop was given to the participants during the training and post-assessment phases of the workshop, which again may have been a source of cognitive load. Ideally, if there were multiple workshops, each workshop could be related to one task and have very specific guidance notes provided to the participant, thereby facilitating them to direct their own learning and skill acquisition through deliberate practice at their own pace. Furthermore, if key questions and skill assessment tasks were included in the material provided, the participant could assess their own learning needs. Furthermore, written feedback could be provided to each participant following the training session in the form of summary feedback, which again would facilitate the participant to undertake self-directed learning in an autonomous manner.

The fourth limitation of the study was that no evaluation of retention of knowledge and skills was carried out at a later stage in the academic year, which would have allowed the researcher to determine the participants' retention of their knowledge and skills.

5.3 Recommendations

i. A haptic ultrasound training device could be used as an effective pedagogical approach in the ultrasound ***Imaging*** module (PHYS 2814) in the stage 2 of the Clinical Measurement Science Programme. In order to avoid issues of cognitive load, the haptic training device could be incorporated into the lecture time slots for demonstration purposes throughout the delivery timeframe of the module.

ii. In order to facilitate and scaffold the learning and skill acquisition of early stage students, repeated training sessions with the haptic training device are optimal in order for them to master this complex task of ultrasound scanning. These multiple workshops could be connected with specific teaching material and could have a specified learning and skill acquisition task associated with each training workshop.

iii. Specific goals for each workshop – as discussed above.

iv. If multiple training workshops were introduced, this could better facilitate more deliberate practice by the students of the specific task at their own pace. This is a key element to andragogy and constructivism learning approaches.

v. Written Summary Feedback could be provided to each of the students following each training workshop for them to better understand how to address their learning and skill acquisition needs. This is important because when new tasks are introduced, the learner needs to be taught and coached in order to provide a scaffold to support learning in incremental amounts. This would represent the Zone of Proximal Development (ZPD) (Kneebone et al., 2004).

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APPENDICES

Appendix A: Ultrasound Imaging Module Descriptor (PHYS 2814)

M1: Module Descriptor Template

Module Code	Pre-requisite Module codes	Co-Requisite Modules code(s)	ISCED Code	Subject Code	ECTS Credits	NFQ Level (CPD)#
PHYS2814	PHYS1807 PHYS1808 PHYS1809				5	

Module Title	
School Responsible:	Physics

Module Overview:
In this section a brief description of the general rationale for, and purpose of, the module should be provided, indicating at whom the module is aimed and if, for example, it is an introductory, basic, intermediate or advanced module. This section should also include if there are discrete module elements / components. This module covers basic concepts in ultrasound physics, including how ultrasound interacts with tissue, how an ultrasound image is formed, transducer technology, ultrasound imaging instrumentation, imaging artefacts Doppler physics, application of Doppler physics – Continuous Wave, Pulsed Wave, Colour and Power Doppler.

Learning Outcomes (LO): (to be numbered) For a 5ECTS module a range of 4-10 LOs is recommended	
On Completion of this module, the learner will be able to	
1	Apply the theory regarding interaction of ultrasound with tissue to describe and analyse image features
2	Identify image artefacts within the image and interpret the cause of such artefacts and evaluate their effect on images
3	Manipulate instrument controls in order to optimise the ultrasound image
4	Interpret how ultrasound can be used to determine the velocity of blood and analyse the haemodynamic features of the Doppler spectra
5	Identify Doppler artefacts and interpret the cause of such artefacts and evaluate their effect on Spectra or images
6	Manipulate instrument controls in order to optimise the Doppler information

Indicative Syllabus:
Indicative syllabus covered in the module and / or in its discrete elements o **Ultrasound Imaging** Principles of ultrasound propagation and the interaction of ultrasound with tissue. Generation of ultrasound and ultrasound transducer technology - piezoelectric effect, transducer characteristics, damping. Sound beam characteristics– effect of transducer crystal diameter on resolution, effect of transducer frequency on beam characteristics, beam focusing, near and far field. Lateral and axial

resolution and slice thickness.

(6 hours)

- **Ultrasound Instrumentation**

Principles and applications of A-mode (Amplitude mode) and M-mode (motion mode).
B-mode imaging: Real time imaging - mechanical and electronic transducers – linear array, sector array, curvilinear array. B-mode Image processing - grey scale display, Time gain compensation, overall gain, output power, frame rate, scan converter, dynamic range, pre and post processing, log compression.

(6 hours)

- **Imaging artefacts**

Origin of artefacts, enhancement, multiple reflections, reverberations, shadowing and refraction.

(2 hours)

- **Doppler Ultrasound**

Doppler effect and Frequency shift due to moving reflector. Doppler signal processing: Insonation angle, reflector speed, aliasing, extracting the Doppler signal, Audible signal analysis, analogue Doppler waveform generation, spectral display characteristics, sample volume size.

(2 hours)

- **Doppler instruments:**

Principles of CW, PW and Colour Doppler. Continuous wave instruments, pulsed wave instruments, Duplex instrumentation, bi-directional and unidirectional Doppler, Colour and Power Doppler.

(6 hours)

- **Principles of Clinical Haemodynamics**

Effects of vessel structure and pathology on clinical haemodynamics. Applications of medical ultrasound in the areas of vascular medicine, cardiology and neurology.

(2 hours)

Learning and Teaching Methods:

Statements about the various types of learning and teaching methods that are used in the delivery of the module
Learning will largely take place in the classroom and in the laboratories. In addition, extensive use will be made of web-based facilities such as 1) appropriate hands-on training using ultrasound systems and training models 2) appropriate problem solving exercises 3) further reading.

Total Teaching Contact Hours	26
Total Self-Directed Learning Hours	74

Module Delivery Duration:

Indicate if the module is normally delivered for example over one semester or less, or over one academic year etc.

Assessment

Assessment Type	**Weighting (%**	**LO Assessment (No.)**
MCQ assessment	10%	1-3
Exam	50%	1-6
Laboratory	40%	1-6

Module Specific Assessment Arrangements (if applicable)		
(a) Derogations from General Assessment Regulations		
(b) Module Assessment Thresholds		
(c) Special Repeat Assessment Arrangements		

Essential Reading

Diagnostic Ultrasound: Physics and Equipment, by Peter Hoskins, Abigail Thrush, Kevin Martin, Tony Whittingham. Greenwich Medical Media; 1 edition (June 2002) ISBN-10: 1841100420 ISBN-13: 978-1841100425.

Diagnostic Ultrasound: Principles and Instruments, F.M. Kremkau, W.B. Saunders Company; 6th edition, 2002.

Physics for Diagnostic Radiology, Second Edition, P. Dendy and B. Heaton, IOP Publishing, ISBN 0 7503 0590 6.

Recommended Reading

Medical Imaging Physics, W.R Hendee, E. Russell Ritenour, Fourth Edition, ISBN 0-471-38226-4.

Supplemental Reading

Doppler ultrasound: physics, instrumentation, and signal processing, Evans, David H., and McDicken, W. Norman, John Wiley & Sons; 2nd edition, 2000.

Web references, journals and other

Ultrasound in Medicine and Biology

Version No:		**Amended By**	
Commencement Date		**Associated Programme Codes**	

Modules that are to be offered as Stand-Alone CPD Programmes must have an NFQ level assigned

*Details of the assessment schedule should be contained in the student handbook for the programme stage.

Date of Academic Council approval …………………………….

Appendix B: Ethical Clearance Letter Ref 14 – 77

Institiúid Teicneolaíochta Átha Cliath, Sráid Caoimhín, Baile Átha Cliath 8, Éire
Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland
www.dit.ie/graduateresearchschool

SCOIL TAIGHDE IARCHÉIME / GRADUATE RESEARCH SCHOOL
Professor Mary McNamara

24th November 2014

Ms. Jacinta Browne

Re: Ethical Clearance Ref 14-77

Dear Jacinta

I am pleased to inform you that the following project:

> ***'An evaluation case study of the role that haptic tools play in the conceptualisation of the diagnostic ultrasound curriculum for 2nd Year Clinical Measurement Science Students'***

which you submitted to the Research Ethical Committee has been approved. The committee would like to wish you very best of luck with the rest of research project. If you have any further queries, please do not hesitate to contact Conor McCague on (01) 402 7920 or at conor.mccague@dit.ie.

Yours sincerely

Dublin Institute of Technology
Research Ethics Committee

Coláistí: Ealaíon & Turasóireacht | Gnó | Innealtóireacht & Timpeallacht Tógtha | Eolaíocht & Sláinte |
Colleges: Arts & Tourism | Business | Engineering & Built Environment | Sciences & Health |

Appendix C: Volunteer Information Sheet and Consent Form

Volunteer Information Sheet – Clinical Measurement Science Students

"An evaluation case study of the role that haptic tools play in the conceptualisation of the diagnostic ultrasound curriculum for 2nd Year Clinical Measurement Science Students"

Introduction

The use of a physical training device (otherwise known as a "haptic training device") within the teaching environment is used to attempt to incorporate balance between theory and practice. Haptic means the sense of touch and haptic tools involve the incorporation of such a device to replicate this sense of touch, it could also be classified as a Technology Enhanced Learning (TEL) device. This approach has been found in previous research studies to improve student's ability to learn complex tasks such as learning about ultrasound imaging and how to carry out an ultrasound scan. In relation to the 2nd year DT229 ***Imaging*** module, students are learning about (1) how the interaction of ultrasound waves and tissue can be used to form an image; (2) what assumptions are programmed into the ultrasound machine to produce this image; (3) why artefacts are produced in the ultrasound images; and (4) how the instrument controls can be used to optimise the information in the images. All of these key areas require that the students evaluate the images in terms of whether they are diagnostic or whether artefacts are present or if further image optimisation can be achieved. However, in the work setting there will also be the requirement to have good hand-eye coordination skills to be able to physically scan the patient using ultrasound. Therefore, by introducing a physical model of simple patient representation in the form of three physical training devices of increasing complexity it will provide you with the opportunity to put into practice your knowledge of ultrasound imaging in a safe environment and allow you to develop your ultrasound imaging skills.

The main aim of the project is to investigate the impact of a series of physical training models on students' learning.

What does the study involve?

To participate in this study you must be a 2nd year student of Clinical Measurement Science and you must decide to "opt-in" to the study. If you decide to participate in this study you will be invited to take part in three workshop sessions involving the use of the ultrasound scanner and the physical training models which will be run by a myself. The session will last between 2-3 hours and it will take place during semester 1. The workshop sessions will take the following format:

1. You will be asked to answer 5 MCQs before and after the use of the physical training device relating to the lecture material covered.
2. During the workshop session I will observe how well you can carry out the different task associated with the workshop session in order to determine whether the training device is useful.
3. At the end of the study I will ask you to rate your experience of using the physical training devices in the workshop session – this will take the form of a short questionnaire.

The performance evaluations carried out as part of this study will not be included in your marks for the module.

Data Storage
No name identifiers will be used on any of the survey or observational data rather a code will be used to identify each student. All data will be coded and the key code will be electronically store in a hard drive with swipe code access, the interview and the survey data from the workshop will be stored in a locked filling cabinet.

Benefits to you
You will have the opportunity to get hands on experience in a safe environment on inanimate objects (i.e. not patients) which will allow you to develop your skills at carrying out complex tasks such as optimising an ultrasound image and carrying out an ultrasound scan of a physical training device, all of which should improve your hand-eye coordination. This study is being undertaken to improve the current teaching approaches taken as part of the degree programme BSc Clinical Measurement Science and it is hoped that this will benefit future students of the programme also.

Voluntary Participation
You have volunteered to participate in this study. You may quit at any time.

If you are interested please attend the scheduled workshop sessions.

Thank you

Dr Jacinta Browne

Phone: 01 -4024737
Email: jacinta.browne@dit.ie

CONSENT FORM

Researcher's Name: (use block capitals) DR JACINTA BROWNE	**Title:** Lecturer
Faculty/School/Department: **Physics**	

Title of Study:
An evaluation case study of the role that haptic tools play in the conceptualisation of the diagnostic ultrasound curriculum for 2nd Year Clinical Measurement Science Students

To be completed by the:
subject/patient/volunteer/informant/interviewee/parent/guardian *(delete as necessary)*

3.1 Have you been fully informed/read the information sheet about this study?
YES/NO

3.2 Have you had an opportunity to ask questions and discuss this study?
YES/NO

1.3. Have you received satisfactory answers to all your questions?
YES/NO

3.4 Have you received enough information about this study and any associated health and safety implications if applicable?
YES/NO

3.5 Do you understand that you are free to withdraw from this study?

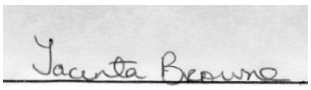
- at any time
- without giving a reason for withdrawing
- without affecting your future relationship with the Institute

YES/NO

3.6 Do you agree to take part in this study the results of which are likely to be published?
YES/NO

3.7 Have you been informed that this consent form shall be kept in the confidence of the researcher?
YES/NO

Signed____ Date ___________________
Name in Block Letters ____

Signature of Researcher  Date __10/10/2016___

Appendix D: Multiple Choice Question (MCQ) Test

Name: _________________

1. Low frequency ultrasound propagating in tissue will:

A be attenuated more than higher frequencies;
B have a greater penetration than higher frequencies;
C penetrate less than higher frequencies;
D give better image quality than higher frequencies;
E increase the speed of sound compared to that for higher frequencies. 5 marks

2. Scattering in ultrasound tissues:

A is an unwanted artefact;
B gives characteristic diagnostic information;
C only occurs at highly reflective boundaries;
D only occurs in fluid filled regions;
E is due to the absorption of ultrasound. 5 marks

3. The focus depth control:

A compensates for attenuation at depth;
B controls the overall gain;
C adjusts the focal zone position;
D controls the output power;
E affects the frame rate. 5 marks

4. The frame rate is:

A the number of frames per second;
B the number of scan lines per second;
C the number of wave cycles per second;
D the number of scan lines per minute;
E the number of pulses per second. 5 marks

5 The swept gain control:

A compensates for attenuation at depth;
B controls the overall gain;
C adjusts the focal zone position;
D controls the output power;
E affects the frame rate. 5 marks

Appendix E: Direct Observation Notes Template

	Pre-Training	Post-Training
Technical Knowledge		
Correct selection of ultrasound transducer	Yes/No	Yes/No
Correct selection of frequency	Yes/No	Yes/No
Correct selection of clinical application	Yes/No	Yes/No
Technical Performance - Correct use of ultrasound system controls for image optimisation		
Use of TGC	Yes/No	Yes/No
Use of overall gain	Yes/No	Yes/No
Use of acoustic power	Yes/No	Yes/No
Use of focal zones	Yes/No	Yes/No
Use of depth	Yes/No	Yes/No
Tissue identification competency		
Specular Reflector	Yes/No	Yes/No
Stochastic scatterer	Yes/No	Yes/No
Hyperechoic lesion	Yes/No	Yes/No
Hypoechoic lesion	Yes/No	Yes/No
Anechoic region	Yes/No	Yes/No
Notes:		
Manipulation of ultrasound transducer		
Approach to scanning the ultrasound training device – systematic / non-systematic		

Appendix F: Questionnaire of the students learning experience with the haptic device

(i) The haptic simulation device created a learning environment in which I felt comfortable.

(ii) The scanning session helped me to develop my confidence in the operation of an ultrasound scanner.

(iii) The scanning session helped me develop my confidence in carrying out an ultrasound examination for example with a patient.

(iv) The session was effective in helping me to integrate theory and practice.

(v) The training device produced a valuable training experience.