A Vygotskian Exploration of Medical Students' Critical Thinking Within Threshold Concept Liminal Spaces

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Transformative conceptual learning is key to gaining disciplinary knowledge and expertise but can be troublesome for students. Since 2004, the explanatory Threshold Concept Framework (TCF) has successfully improved student outcomes by identifying and targeting these troublesome transformative concepts with pedagogical support. Recent TCF research has focused on the 'liminal space', the time-space where students struggle to grasp transformative concepts. However, no research has fully mapped this learning journey to transformation considering the contribution of critical thinking to this cognitive process.

A qualitative approach was used to investigate how critical thinking acts within the liminal space during conceptual learning in undergraduate medicine. Experts and students at an Australian university medical school were interviewed about their experiences of threshold concepts in learning and teaching evidence-based practice and medical biostatistics. This led to a year-long case-study series of students from across the medicine program. Participants were invited to keep a reflective journal of the critical thinking employed at troublesome conceptual learning moments. Journal and interview data were analysed using an abductive analysis method that applied a combined theoretical framework of the TCF and Vygotskian educational development theory.

This Vygotskian exploration of transformative learning episodes revealed three main intersections: conceptual learning as a system; language and thinking; and the zone of proximal development (ZPD) and liminal space. Iterative analysis revealed that students experience challenging learning thresholds where individualised conceptual systematisation creates distinct disciplinary conceptual elements. Assimilation of key overarching concepts initiates a core transformation of knowledge and disciplinary perspectives, leading to new ways of thinking and practising with augmented clinical expertise. Most interestingly, language acts as the central cognitive bridge that initiates and enables critical thinking within the ZPD/liminal space. Dialogue with experts and peers was important for student learning, but self-teaching, as inner speech, was significant in exploiting crucial critical thinking steps that unlock transformation. Recommendations are made to emphasise and nurture this intrinsic language-critical thinking integrator system to enhance student conceptual metamorphosis towards medical practitioner identity.

ABSTRACT

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This PhD journey has taken nearly half your lifetime; you've been amazingly patient with your mother.

I dedicate this thesis to you, my students and your fellow Generation Z's. May you continue to enjoy learning and metamorphose many times to mature into wise, adaptive critical practitioners.

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LEARNING IS INHERENTLY TROUBLESOME

"A word devoid of thought is a dead thing, and a thought unembodied in words remains a shadow."

(Vygotsky, 1986, p. 255)

When we are born, we have an innate ability to think. From this thinking, through exposure to experiences and circumstances, we develop our own peculiar knowledge, understanding and viewpoint of the world that adjusts and builds throughout our lives. We need this understanding and different ways of thinking to survive the fast-moving, multi-lingual, complex cultures of modern society. As Bruner (1997, p. 67) eloquently states: "What is unique about us as a species is that we not only adapt to the natural and social worlds through appropriate actions, but we also create theories and stories to help us *understand* and even *explain* the world and our actions in it" (emphasis in original). He goes on to note that Vygotsky believed that mental growth progressed only when language and culture work together through social or instructive collaboration to provide "symbolic tools" that enable "mastery of concrete particulars to higher mastery of the abstract" (Bruner, 1997, p. 68). Interestingly, Bruner contends that Vygotsky's main inquiry was about how these "symbolic tools" derived from language and the socio-cultural context go from external to the mind to become active, conscious and unconscious thoughts (Bruner, 1997, p. 68).

1.1 THE TROUBLESOME LEARNING JOURNEY

Conceptualisation is a basic intellectual function, generally recognised as the basis of gaining knowledge at all ages and across all cultures, though, this is not necessarily an easy or unconscious one. Over the centuries of history of human civilization, research into this essential learning process and its purpose in society has derived from multiple perspectives: sociological, psychological, philosophical and educational. However, despite this large body of research and recent advances in medical technology that, for the first time, enable us to visualise the brain in action, it remains uncertain what is happening within the mind of the learner; how do we gain mastery of conceptual knowledge? Myriad research presents acceptable theoretical models, but there is less useful empirical research available on the essential thinking happening within this process. One consensus is that mastery of knowledge is a complex and singular process, contributing to the difficulty of exploratory research.

1.1.1 Conceptual Learning

As human beings, we strive to learn above and beyond the basic needs of living. Even the desperately poor, who live on the knife-edge of survival, endeavour to know more about their environment. This thirst for knowledge goes hand in hand with an inherent desire to understand and rationalise the world we live in, to delve further into the intellectual realm. Thus, philosophers since ancient times have tested their wits and reputations on attempting to understand the world, to explore the ways we think and perceive our environment. One way of understanding knowledge and thought is to conclude this is of our own making; concepts are our way of viewing the world, of making sense of what we see and hear around us, of building our inner world to understand the external one.

Clearly, as teachers or researchers it would be beneficial if we could literally see into the student's mind to observe what is going on when these processes are taking place. This is now possible with advances in nuclear imaging; brain imaging technologies can provide high-resolution images of the brain in action, when cognition and language are taking place (Fernyhough, 2016, p. 71). For the first time it is possible to map areas of consciousness and emotions, as well as damage (Parkinson's disease, mental health problems). These methods can be used for symptom diagnosis and in theory can predict treatment outcome and track treatment processes (Woo, Chang, Lindquist, & Wager, 2017). However, these images are hard to interpret in terms of the dynamics of the thought processes. They invariably show connections from specialist brain area to specialist brain area, so are useful for identifying regions and routes in the brain that are related to thinking and learning. Yet, even if we demarcate these operations, our knowledge of what is happening is so unclear that it would be difficult to interpret it adequately. Block (2015), a leading US philosopher in psychology-neuroscience, sums up this drawback nicely by paraphrasing Kant: "concepts without data are empty; data without concepts are blind" (p. 175). In order to interpret the remarkable images of the brain that we see with this technology, we first need to understand the psychological pathways that underpin the processes. Language is the clearest human way of learning and communicating, so it makes perfect sense to use discourse-based research techniques to explore how we think for learning of conceptual knowledge.

1.1.2 Disciplinary Threshold Concepts

A relatively new educational approach has been making significant headway in detailing the conceptual learning journey. Early at the turn of this millennium, two separate but parallel groundbreaking educational research projects were launched, one in the USA and one in the UK. The UK project coined the phrase "ways of thinking and practising" (Meyer & Land, 2003, p. 9) to describe the way conceptual learning provides the student with the wherewithal to think and act like an apprentice expert within a discipline (Entwistle, 2005, p. 5). The USA project concentrated on identifying the disciplinary "bottlenecks" where students get stuck in their learning (Bonner, Lotter, & Harwood, 2004, p. 26). These endeavours were groundbreaking as they initiated a renewed examination of the points in disciplinary conceptual learning where learners hesitate or get stuck. At the same time, they provided teachers with new ideas on how to guide the learner through this troublesome learning. This sparked an enthusiastic re-examination of conceptual learning across the disciplines in higher education.

In addition, the research touched on the nature of the discipline expert and how to support students to gain this mastery. Academics in both the 'hard' (e.g. economics, physics) and 'soft' disciplines (e.g. biology, literature) have striven to clarify what sets each discipline apart from its neighbouring disciplines. This approach has developed into the Threshold Concept Framework (TCF), based in part on earlier work by Perkins (1999, p. 11) on analysing "troublesome knowledge," the detailed conceptual frameworks of Entwistle (Entwistle, 2003, 2005) and the enlightening idea of "ways of thinking and practising" by the UK ETL project (Entwistle, McCune, & Hounsell, 2002, p. 2). This framework provides clear theoretical explanatory approach and a practical "actionable" way of examining disciplinary curricula (Land, Meyer, & Smith, 2008, p. xi). Essentially, the TCF enables identification and then dissection of those troublesome and transformative concepts that students find so difficult to understand.

This research has informed the disciplines, as well as the professions and practices that higher education nurtures. Moreover, it has provided information to help teaching across the educational spectrum from kindergarten through to higher education and beyond to continuing professional development. By providing information on how to support new students to learn the disciplines we maintain the tradition of graduates following in our footsteps to become the next generation of discipline experts.

For my research on the pivotal moment of conceptual learning, I chose to limit my research of conceptual learning to threshold concepts. Meyer and Land (2003, 2005) summarise the key characteristics of threshold concepts as follows. The learning is *transformative*; the learner will change identity or shift their view of the subject substantially. Additionally, there tends to be an emotional element to this experience, which occasionally is a 'eureka' moment. However, these epistemological and ontological shifts might occur slower or pass unnoticed, until made obvious by a later increased ability in disciplinary discourse (Meyer & Land, 2005, p. 4). There is often an element of *troublesome knowledge*; the knowledge is problematic and difficult to comprehend. This might be due to the type of knowledge it contains; alien or counterintuitive knowledge is inherently difficult for the learner – it challenges current knowledge, cultural understandings or can even be incoherent when first encountered (Perkins, 1999). Likewise, the new concept's language may be troublesome, due to lexical ambiguity, terminology, and the inherent semiotics and signification that the conceptual learning provokes (Meyer & Land, 2005, p. 9). Mostly, this transformation is *irreversible* – in the sense that the understanding, once experienced, is hard to forget or unlearn (Meyer & Land, 2005, p. 4). Similar to learning to ride a bike, it becomes intrinsic, automatic. In addition, the learning is *integrative*; the understanding of a concept can reveal interrelated understandings, for instance other concepts appear more understandable or connected, or a student may be able to learn another related concept more easily (Meyer & Land, 2005, p. 4). Often this whole process occurs within a *bounded* disciplinary system that establishes the relevant academic territory. Other elements have been suggested and developed since the original papers, including *discursive*, *reconstitutive* and *liminal* (Land, Meyer, & Baillie, 2010). These add important detail to the transformative learning journey and are explained below.

1.1.3 The Learning Point: The Liminal Space

Further research around threshold concept learning has targeted the learning process that lead to transformative conceptual learning, by examining the so-called liminal space (Meyer & Land, 2005). This term comes from the Latin word *līmen*, which means threshold from 'liminal', defined as: "1. Relating to a transitional or initial stage of a process; 2.

Occupying a position at, or on both sides of, a boundary or threshold" (OED, 2019). Both definitions are pertinent here, as liminality was borrowed from its anthropology, so relates to the ritual cultural processes introduced by Arnold van Gennep, *Les Rites de Passage* (1909), with thresholds on entering and leaving the space (Land et al., 2008). By using liminal in conjunction with the term 'space', Meyer and Land have provided a term that has both a temporal and a spatial meaning. This liminal space is the challenging learning space where learners can get stuck and often lose their way before eventually "crossing conceptual gateways or 'portals'… to arrive at important new understandings" (Land, Meyer and Smith, 2008, p. ix), see Figure 1.1.

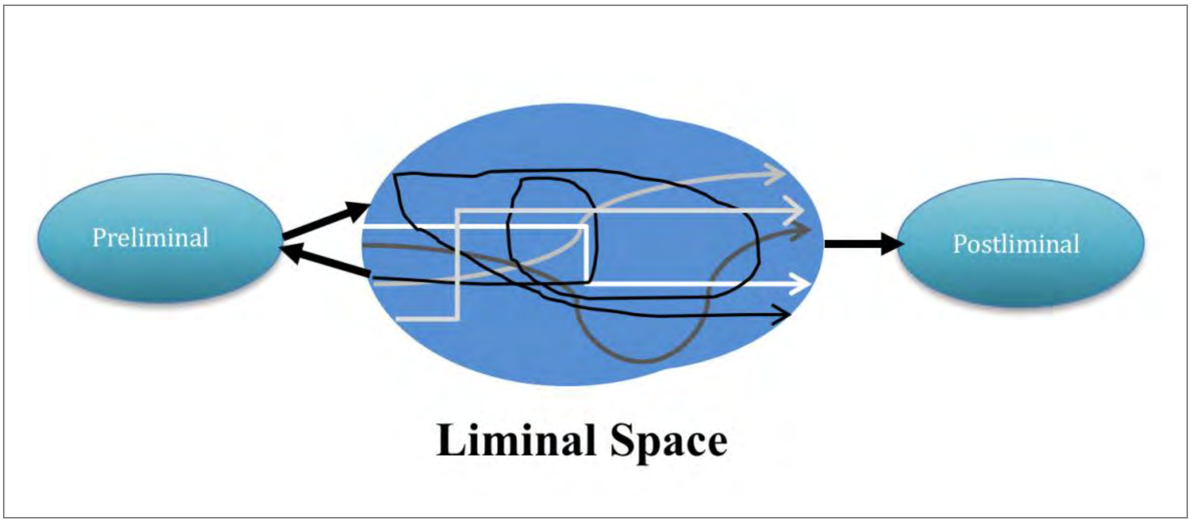

Figure 1.1 Representation of individual student liminal learning journeys
(Based on Kabo and Baillie 2010, p. 307)

Metaphorically, a learner crosses a threshold into the post-liminal space, but this requires a discursive approach of active explanation and reasoning to gain a higher level of understanding, resulting in a reconstitutive change in her ways of knowing and practising (Land et al., 2010). Other research has focussed on understanding the "underlying game" or "the episteme," which is the disciplinary way of knowing that allows learners to initiate and navigate this conceptual learning (Land et al., 2010, p. xxxv). This has highlighted that conceptual learning is vital to the acquisition of disciplinarily knowledge and is necessarily complex. However, at the same time it has revealed gaps in our understanding, including the conceptual thinking process, which covertly acts within the liminal space.

As the liminal space is where the majority of learning happens, it would be expected to involve active critical thinking on the part of the learner and active support for this by the teacher (Middendorf & Pace, 2004). Unfortunately, its inherent complexity makes critical thinking very hard to examine in detail; it has a slippery nature. In explaining conceptual aspects of critical thinking, it is hard to pin down except in terms of basic skills and dispositions. Moreover, if critical thinking is explored by examining its dispositional element, the skill element (its practical, operational aspect) can be overlooked, and vice versa (Perkins, 2008). Furthermore, if these skills or dispositions are examined without considering the emotional elements of this thinking then another key characteristic is neglected (Moon, 2008, p. 54). Separating any of these vital elements of critical thinking dissociates them from the learner's cognitive processes and the original context. Hence, in this thesis, I argue that conceptual knowledge and the procedural processes that initiate and accompany this learning are inextricably linked and, where possible, must be examined as a whole and in action.

1.2 SITUATING THE THESIS

My original training was in medicine with specialisation in public health medicine in the UK, but for the past 15 years I have been lecturing at the University of New South Wales. My current position at UNSW is Senior Lecturer in the Office of Medical Education, where my main teaching role is to convene a medicine program element, Quality of Medical Practice (QMP). This is the source of my research questions. The setting of any research is of paramount importance, so the context and curriculum warrants introduction as background to this thesis.

1.2.1 The Learning Environment

Medical degrees across Australia are organised and managed by university faculties, but contain a significant practice-based, clinical element that takes place in health care settings funded by state governments. There is good quality research on the development of the medical student from school-leaver, through the undergraduate medical curriculum, to clinical practitioner graduate. However, there is less information about what happens at key transformational points in learning. These moments are hard to examine – they are hidden from the teacher in the student's mind and may be just as mysterious to the learner herself.

Assisting this cognitive development are various other elements, including learning activities (program and external), parallel conceptual non-transformational and transformational learning, and other developmental and procedural skills. In addition, there is the immediate environment of the medical program, the courses and elements of practice that make up the undergraduate medical curriculum, and the teaching and administrative staff, faculty and clinical schools. Also, there is the wider influence of the stakeholders, including the university bodies, secondary schools, hospitals and health service systems, the accreditation body (the Australian Medical Council, AMC), the specialist royal colleges and other professional bodies. These have authority and influence on the medical program, the curriculum, its staff and its students via funding, accreditation, policy, training opportunities, workforce demands and policies and professional expectations.

Undergraduate medicine courses in Australia are taught through an integrated curriculum, combining the learning of medical science and clinical medicine with essential elements such as communication and clinical skills, evidence-based medicine, ethics and legal practice, and research skills. At UNSW, all students spend their early years (Phase 1; first and second years) mainly on campus where they learn medical and clinical science content and basic clinical skills. In Phase 2 (third year), they move to a timetable of two days on campus, three days of clinical placement, followed by their research year (Phase 2, fourth year). This leads to a clinical placement schedule in Phase 3 (fifth and six years). In Phase 1, multiple disciplines are taught during each integrated course using lectures, tutorials and practical learning activities. Weekly small group teaching of scenario-based learning is designed to assist students to integrate their new scientific knowledge across disciplines and with clinical science (Balasooriya, Hughes, & Toohey, 2009). This is in stark contrast to the discarded traditional curriculum of two years of medical science, followed by three years of clinical practice. The modern curriculum format at UNSW commenced in 2004 and reflects the multi-disciplinary nature of medicine as an integrative professional discipline.

The Discipline

Medicine at undergraduate level involves learning medical and clinical sciences alongside skills to apply this knowledge as newly qualified intern-level doctors. It takes five to six years for an undergraduate student to graduate and at that point they must be capable of putting knowledge into practice safely. At UNSW, Quality of Medical Practice focuses on students learning some of these key skills for clinical practice. This is a new disciplinary element of the program; a combination of evidence-based practice (EBP) and quality and safety in healthcare. EBP is introduced to first year students as the best way of practising medicine. It requires basic research skills and also a basic understanding of medical biostatistics. These are learned and integrated with other key clinical skills such as communication (e.g. good history-taking). The desired student learning outcome is high-quality decision-making that maximises patient management and outcomes.

EBP has its origins as evidence-based medicine during 1980s – developed by concerned physicians in response to increasing volume and complexity of clinical research evidence. It is a way to structure and assist doctors in choosing the best quality evidence and adapting this appropriately for each patient. The original definition for evidence-based medicine (EBM) required "the integration of the best research evidence with our clinical expertise and our patient's unique values and circumstances" (Straus, Glasziou, Richardson and Haynes, 2011, p. 1). The principal process for evidence-based medicine is the five-step cycle starting with asking clinical questions and cycling through to assessing the process undertaken (see Figure 1.2, below). I prefer to call this the evidence-based practice (EBP) cycle, in preference to EBM, as healthcare is interprofessional and all workers should practise EBP.

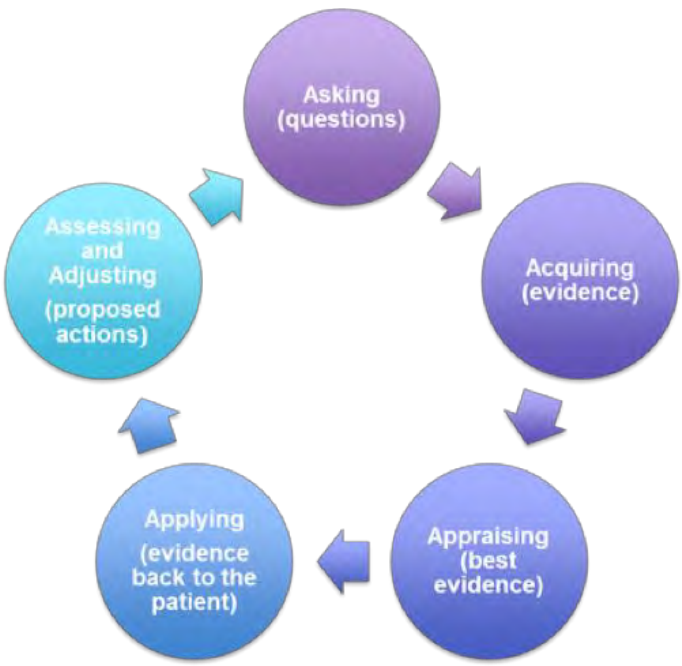

Figure 1.2 The EBP cycle

(Based on Straus et al. 2011; Dawes et al, 2005) Step 1: Asking clinical questions; Step 2: Acquiring evidence; Step 3: Appraising best evidence; Step 4: Applying evidence back to the patient; Step 5: Assessing and adjusting the actions taken.

At UNSW, we responded to the publication of the Sicily Statement on Evidence-based Practice (Dawes et al, 2005) by following these internationally accepted principles and clear EBP definition in the design of a curriculum that integrated clinical learning with skills for evidence-based practice. From the beginning, this was a fully blended curriculum with online resources supporting and enhancing face-to-face learning activities within virtually all of the courses, across all six years of the medical program. Student learning objectives were explicitly linked to the 5-steps of EBP and aligned directly to formative and summative assessments. I was radical in introducing EBP to first-year students during their first ever course, prior to their gaining clinical experience. This includes teaching basic medical biostatistics, to ensure that students can read and understand published medical research, and as preparation towards their research year. My rationale for this is that new students need to learn EBP as the preferred approach to clinical practice, so it needs to be taught early. However, students are conceptually naïve about practice at this stage and can find the application step hard to fully understand. The QMP curriculum has the ultimate aim of assisting students to graduate as critical and safe medical practitioners for "best practice" in healthcare (Dawes et al, 2005, p. 1).

UNSW medical students are mostly aged 18-25 years old, with a few starting younger and very few mature students. These students are driven, curious, and hard-working, but they are also strategic learners, stressed by a complex, integrated full-time timetable. They are frequently anxious regarding their learning goals and the regular barrier examinations that mark their transition across the program (Hope & Henderson, 2014). Despite their intelligence and dogged determination to learn everything they deem important in the curriculum, I found that students struggled with my curriculum. Fortunately, in 2007, I was introduced to the TCF when taking a course for a Graduate Certificate of University Learning and Teaching. Since then, I have utilised this research to examine and remodel my teaching practice and curriculum and discovered major transformative concepts in EBP and medical biostatistics, as depicted in Figure 1.3 below (Quinnell & Thompson, 2010). Additionally, I made the disquieting discovery that more than a third of the medical students were *numerophobic*, meaning that they had problems learning concepts involving mathematics or numbers (R. Thompson, 2008). This led to collaborative research into numerophobia and poor transference of quantitative skills as barriers to conceptual understanding in my discipline and 'soft' science disciplines (Quinnell, Thompson, & LeBard, 2013). Despite improving my curriculum using the TCF and other approaches I realised that I had more to learn if I was wanted to improve my students' learning outcomes. Therefore, this thesis details two learning journeys; my personal development journey runs parallel to the thesis research exploring the learning journey of my students.

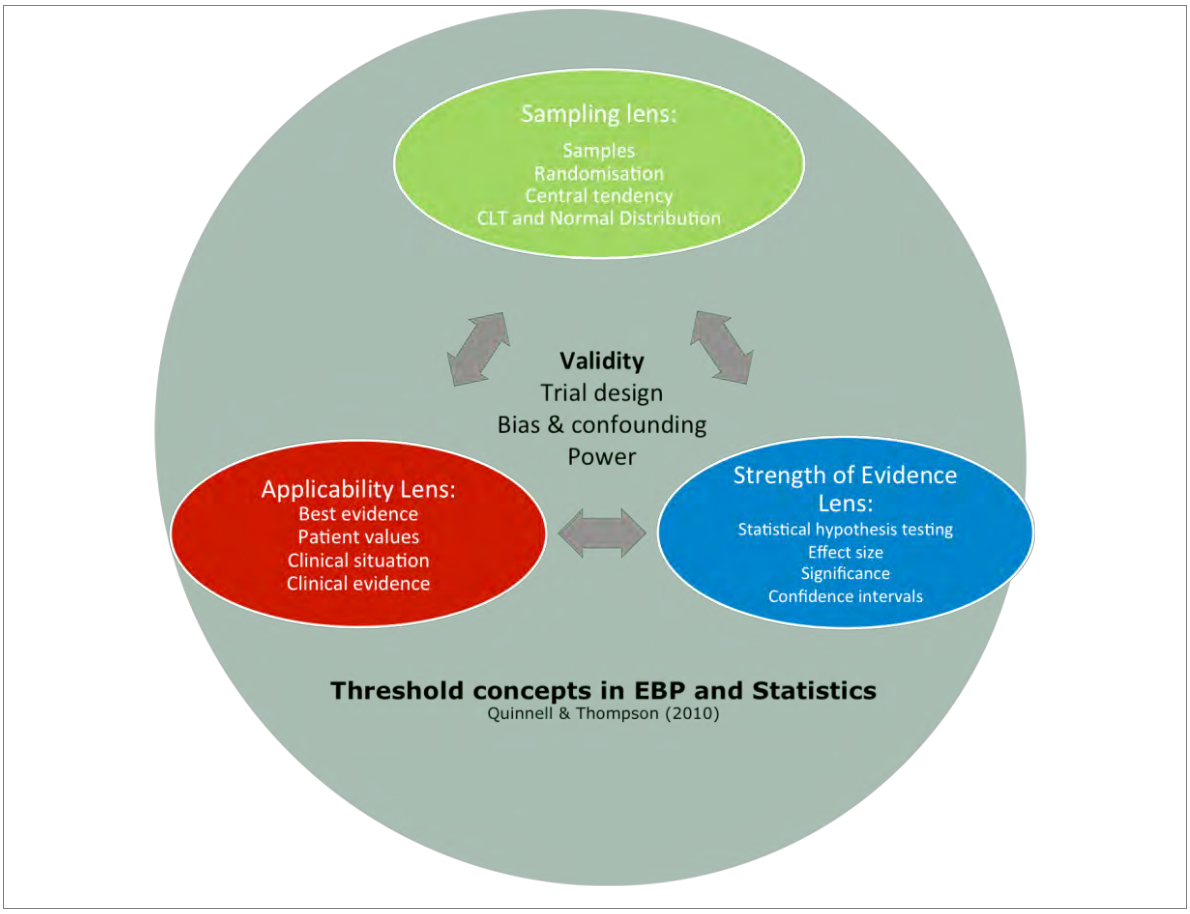

Figure 1.3 Diagram representing the overarching threshold concept lenses of sampling, strength of evidence and applicability

The main threshold knowledge and procedural concepts are listed for each. Refined for teaching purposes from work published in (Quinnell & Thompson, 2010)

1.2.2 Perspectives on Conceptual Learning

From an initial broad review of the literature, key research perspectives for examining conceptual learning were identified. Some of these perspectives resonated more with my way of thinking and the research questions I was interested in, and these lenses were chosen to explore conceptual learning and critical thinking. Their broad perspectives can be categorised as: philosophical, psychological, sociological, educational and disciplinary context. The philosophical lens provides research that ranges from the theoretical to the applied approach, e.g. the rational, critical study of concepts and principles of critical thinking to the educational application, such as models for teaching. The philosophical approach can also be applied through any of the other lenses; often, the major thinkers in these other fields have a philosophical leaning to their perspective. In contrast, the psychological lens, specifically cognitive psychology, is a vast area of research that emphasises a neuroscience perspective but can take on a more philosophical position. The sociological lens acknowledges the influence on the learner and university of society, culture, family, upbringing, rules and power structures. The educational lens is the area that I am most interested in as this is the context of the research. This tends to be grounded in philosophical enquiry but influenced by a long-standing relationship with the more empirical, cognitive psychological perspective. It is an essential lens to use here as higher education is the context.

Lastly, the discipline context of medical education is relevant. It is historically insular and notoriously metric-based in its approach to research. Surprisingly, considering the current patient-centred approach to medicine, research support and funding fails to promote philosophical and sociocultural perspectives through qualitative methodology, except within the related disciplines of public health and sociology (Martin & Félix-Bortolotti, 2014). Lead journals in medicine fail to publish qualitative research, as it is seen as "'low priority' … 'not of interest to our readers'" (Greenhalgh et al., 2016). This attitude is accentuated by current innovations in utilising *big data* in healthcare; this is data that is collected routinely or strategically on the back of the massive growth of ubiquitous information systems (Gandomi & Haider, 2015). There is evidence that these big data number-crunching and data-mining methods are failing to comprehend "real-time individual" patient needs, despite being capable of bridging the gap between clinical practice and research (Martin & Félix-Bortolotti, 2014). For my thesis, I purposefully sought a supervisor within the School of Education (Faculty of Arts and Social Sciences), who could advise and support an exploratory, qualitative approach using mainly educational, psychological and sociological perspectives. This opened up a whole new way of viewing my curriculum, and allowed me a detailed, student-centred focus in contrast to the faculty's emphasis on a quantitative analytical approach.

1.2.3 Focus and Boundaries of this Thesis

Researchers have endeavoured to identify the fundamental nature of the process that promotes transformative and reconstitutive conceptual learning. Unfortunately, gaps in understanding persist, especially regarding the processes that the learner employs to successfully traverse the liminal space and gain essential transformative understanding. It is postulated that, in mastering a threshold concept, a learner passes through two conceptual stages, the preliminal, followed by the liminal, in order to reach the anticipated postliminal stage (Land, Meyer, & Baillie, 2010). On reaching this post-liminal stage requisite disciplinary knowledge has been gained, but in so doing, the learner has undergone a shift in perspective, enabling their engagement in a new or higher-level disciplinary discourse (Land, Meyer, & Baillie, 2010). This crossing of the liminal threshold stages is thought to be a unique cognitive and affective learning process for every individual (Rattray, 2016; J. A. Timmermans, 2010). Indeed, this process and the liminal space it occurs in, appears to be extremely complex and learner-specific, and has defied examination in terms of the skills required. The impact of excessive cognitive load on learning within the liminal space is recognised as a further inhibitor of learning (Ross, Taylor, Hughes, Kofod, et al., 2010). Hence, the theoretical construct of the liminal space has been described as a "black box" that contains many unknowns, gaps and silences, still waiting to be explored (Land, Rattray, & Vivian, 2014, p. 201). Therefore, there is a pressing need to understand more detail how individual students are changing in this epistemological and ontological process. This "inter-individual variation" is a new focus in the TCF research (Baillie, Bowden, & Meyer, 2013, p. 229), but is less straight-forward than examining disciplinary knowledge retention, which is comparatively easy to observe, test and demonstrate in our students (Land & Meyer, 2010).

In undergraduate medical training, it is not clear how students gain transformative knowledge and develop critical thinking skills. No one has successfully mapped the individual journey to transformative knowledge or examined how critical thinking practice impacts on this process. Hence, exploring the factors and processes that lead up to transformation and conceptual enlightenment was my goal. Consequently, my thesis examines the learning processes within the liminal space, to discover how development of medical students' critical thinking practice intersects with conceptual learning. To achieve this, the thesis took an educational psychology approach without extending into this new realm of cognitive psychology-neuroscience or delving too deeply into philosophical approaches to this research. The ultimate aim was to find ways to assist students as they progress from keen school leaver to competent graduate, medical internship and the responsibilities of major life and death decisions. This research focuses on student learning of EBP and medical biostatistics as guided by the QMP element across the medicine program curriculum at UNSW.

1.3 USING VYGOTSKY TO ILLUMINATE THE LIMINAL SPACE

In dismantling the transformational conceptual learning process to examine it, we can lose sight of what is actually happening in the mind of the student at the moment of transformation, within the liminal space, the "black box" of transformational conceptual learning (Land, Rattray, & Vivian, 2014, p.201). This process needs to be viewed as a whole to observe its full complexity. Consequentially, this thesis aimed to examine the holistic process in greater detail using theory that has the capacity to look at both the whole and the components of a working process.

1.3.1 Vygotsky's Theories

According to pivotal theories arising from the 20th century developmental psychologists Piaget (1952) and Vygotsky (1998c), each child must come to understand and structure their basic and more advanced concepts as an essential developmental step to maturing and living within the world. Indeed, Vygotsky proposed that we structure our intellectual world through a conceptual framework to navigate our knowledge and give it sociocultural meaning (Vygotsky, 2012, p. 184). For instance, the learning of language requires the understanding of many simple, complex and even transformational concepts. Once a child has mastered basic language, whether spoken or signed, she can use language to learn and convey knowledge and understanding to others. Without this ability to learn and to use language to communicate to self and others, a child would struggle to master knowledge and can be isolated from their cultural group (Vygotsky, 2012).

Vygotsky was intrigued with this relationship between language and thinking. His ideas and theories provide valuable insights into the complexity of how speech is involved in thinking. For example, Vygotsky and his followers have argued that inner speech and external speech both have roles in the development and action of thought: "…in external speech thought is embodied in words, in inner speech words must sublimate in order to bring forth a thought" (Kozulin, 1986, p.liii). In his related theories on conceptual learning and mastery, Vygotsky challenged the prevailing order; he brought cultural and environmental influences to bear on the dominant trend of lofty theorising on thought and mind that dissociated it from action and the world. For instance, he believed that a child's development arose from practical experience and for use in practice, whereas instruction with teacher or better-informed peer was key to the learning of more complex, "non-spontaneous," "academic," school-learnt concepts (Vygotsky, 2012, p. 181). Furthermore, he believed that the role of language in developmental and conceptual learning was vital. Thinking and language according to Vygotsky (2012, p. 181), is crucial to intellectual perception and the "making of meaning" of the world. The ZPD is vital in this process as the interactional learning moment supported by the instructor or more learned peer. Many current educational approaches promote this form of learning and the scaffolding strategies that derive from it (Hammond, 2001).

1.3.2 Vygotsky, Critical Thinking and the Liminal Space

A lack of a strong evidence-base within medical education provided good reason to concentrate on the underlying philosophy and theory of critical thinking. Through reading Vygotsky and deepening my understanding of conceptual learning, I have taken a theoretical leap forward, to focus more clearly on the conceptual intersection point, the liminal space: the crucial moment of transformation in student learning. This moment is crucial to understanding critical thinking and therefore the possibility of assisting students in their understanding of fundamental conceptual learning. In the next two chapters, relevant theories will be explained and critiqued to show how they were moulded to produce a theoretical framework for research into the conceptual intersections of the liminal space.

Learning a discipline is not straightforward and higher education is a demanding place to study. Disciplinary knowledge is troublesome and tricky to learn, due to its conceptual nature, and also as it is littered with theoretical fallacies, peculiar dead ends and ideas leftover from bygone eras. How we think and learn concepts is not clear, despite advances in the visualisation of the neural networks as they function. Consequently, this is a complex area to research and one where there is a great deal to investigate and understand. Furthermore, quality medical graduates are vital to a good and safe health service. Consequently, my three research questions aimed to fill three gaps in current understanding (see Figure 1.4).

1. *What are the troublesome and transformational conceptual development domains in learning evidence-based practice and statistics for medical students at UNSW?*
2. *What are the critical thinking skills that enable this troublesome transformational learning for medical students at UNSW?*
3. *Does a Vygotskian-TCF framework approach add to the understanding of transformational conceptual learning?*

Figure 1.4 Thesis research questions

The first research question aimed to detail the conceptual structure of my discipline topics of EBP and medical biostatistics. This was a necessary first step in order to research the second question. The conceptual elements were mapped through an accepted triangulation method by interviewing experts, learners and teachers of the medical program (Meyer & Timmermans, 2016). Once the discipline transformative concepts and their relationships were detailed, a case-series study was employed to answer the second research question. This was the examination of the thinking processes that take place within the liminal space of threshold concepts for undergraduate medical students, with the aim of improving the current curriculum. The study collected interview and reflective data on students' use of critical thinking during these transformative moments. This was analysed using an abductive approach, using Vygotskian theory combined with the TCF. Finally, the Vygotskian-TCF framework was evaluated to see if it could be useful for future research.

1.3.3 Summarising the Thesis

My research uses relevant Vygotskian theories and the TCF to explore how students use critical thinking in transformative learning. Overall, an interpretivist theoretical paradigm was employed to explore the three research questions using a constructivist, socio-cultural approach with abductive analysis of qualitative data that brings the theoretical framework to the fore in approaching the data. This relatively novel method of analysis approach worked well, revealing self-organising conceptual systematisation within my discipline of EBP and medical biostatistics. These conceptual elements appear to integrate into complexes of overarching concepts that alter students' epistemological and ontological perceptions. Further, language acts as a cognitive bridge by initiating and facilitating critical thinking within the liminal space. The critical thinking steps facilitating transformation were examined in detail. In evaluating the research process, the Vygotskian approach combined well with the TCF; it was dynamically synergistic and further research approaches are recommended using this new analytical framework.

In summary, this thesis reports on an exploration of the whole transformative conceptual learning journey. It follows a standard structure with this first chapter providing an introduction to the topic of the thesis, explaining the rationale and significance of the research questions and the methodological approach. Chapter 2 describes and critiques the relevant literature. Using relevant perspectives, it analyses the previous and current research on conceptual knowledge and learning, and also illustrates the significance and consequence of the research. Chapter 3 explains the chosen theoretical methodology and then details and evaluates the research methods employed. Subsequently, Chapters 4, 5 and 6 present my research data analysis, interpretations and discussion. Lastly in Chapter 7, I draw the thesis to a conclusion via summary discussion, with recommendations for practice and suggestions for future directions for research.

CHAPTER 2:
CONCEPTUAL LEARNING, CRITICAL THINKING AND VYGOTSKY

"We use consciousness to denote awareness of the activity of the mind – the consciousness of being conscious."

(Vygotsky, 2012, p. 180)

The previous chapter introduced the major areas of research, establishing the research themes of this thesis. This second chapter examines more critically, through various key perspectives, the current knowledge base and understanding of critical thinking and relevant conceptual learning theories. This literature review evaluates the relevant research and positions my thesis within the field of higher education to provide a critical background to the thesis. My research focuses on a medicine program that enrols on average 280 students a year, who typically arrive at university directly from their final year at secondary school. This thesis investigates the experience of these students in their learning of evidence-based practice and medical biostatistics. Specifically, it explores the ways that students use critical thinking and language to overcome difficult transformative conceptual moments in their learning journeys. As the literature search unfolded, it was clear that I was examining not one, but three topic intersections: 1) conceptual learning and critical thinking; 2) threshold concept framework and Vygotskian conceptual theory; 3) expertise and learning. I have focused this chapter's critical evaluation on the first of these two intersections, and the third is essential to the methodology in Chapter 3. Overall, this critical literature review defends the importance of this thesis within the present-day research context and sets the scene for the justification of the theoretical approaches used in the methodology, detailed in the next chapter.

2.1 THE PROCESS: CONCEPTUAL LEARNING

Conceptual learning is key to the passing on of knowledge from one generation to the next; it is the foundation of disciplinary knowledge as we know it. In learning concepts, we gain expertise, with expertise we gain power and influence. One of the most powerful institutions within society is the University with higher education leading research, innovation and advocacy. This thesis examines one small part of this, taking a predominantly constructivist, socio-cultural educational perspective.

2.1.1 The Nature of Knowledge and Thinking

A social theory view of the world maintains that the foundation of human society rests on knowledge passed on through generations. New innovations and ways of thinking shape future societies, politics, economies and cultures. Children interact with adults, their more learned peers, younger relatives and friends. Growing up within this socio-cultural 'classroom' a child learns basic understandings to negotiate and survive her local world. As she grows up, she seeks to learn more and curiosity leads her to higher-level conceptual learning, even if she is not fortunate enough to access formal education. There have been many definitions of knowledge across the ages, but a modern sociological viewpoint is provided by Bell (1974, p. 175) who summarised knowledge as "a set of organized statements of facts or ideas, presenting a reasoned judgement or an experimental result, which is transmitted to others through some communication medium in some systematic form." This definition is still in popular use, as it has been found useful in the technological-communication era. For the sociological necessity of measuring the growth of knowledge, Bell (1974, p. 176) provided a more operational definition of knowledge as "that which is objectively known, an intellectual property," specifically positioning produced, published or copyrighted knowledge as a social product and cost, rather than belonging to the individual (Cortada, 1998, p. 175). In contrast, Vygotsky's whole life's work resounds with his belief that the socio-cultural world constructs and sustains knowledge of society and for society through collaborative dialogue (Wells, 2004). He believed that the individual learner gains knowledge through interactions with the more knowledgeable peers or teachers. Hence this has contributed to constructivism learning theories that emphasise the individual and social community. This has led to criticism that our current understanding of knowledge construction can lead to exclusivity regarding the human epistemology, as Vygotsky's focus on the influence of the social takes this back to the individual (Lui & Matthews, 2005).

Within higher education, it has been said that the University is knowledge and knowledge is the University, "inescapably joined together, and - while somewhat asymmetrical - the relationship is reciprocal" (Barnett & Bengtsen, 2017, p. 1). Furthermore, within the University knowledge and power have been demonstrated to be held within disciplines, distributed according to political and hierarchical relationships and competition (Becher & Trowler, 2001). University disciplines play an accepted role within society, producing leaders, politicians, researchers, advocates, teachers and professionals. For this thesis, conceptual learning is considered to centre around disciplines as defined and delineated by relevant experts, taking an academic disciplinary epistemic view (Entwistle, 2005, p. 71). The identification and learning of these disciplines and the development of their ways of thinking and practice being accepted as the foundation of mastery and expertise. Thus, this research relies on disciplinary experts, student learners and novices as the key source of multiple versions of reality in conceptual learning in higher education.

2.1.2 Conceptual Learning in Higher Education

To understand critical thinking within the higher education context, it is necessary to first understand student learning theory. Paul Barnett and Stephen Brookfield are two internationally renowned researchers from the UK and USA respectively, who have been advocating reforms in education since the 1980's. Using analogous sociological approaches and following in the footsteps of Dewey's democratic advocacy (Westbrook, 1993), they have provided research-based evidence, policy advice and governmental service that has altered the shape of higher education. Moreover, they agree that adult learning should be more than simple formal education taught at university or college and, therefore, propose that there should be a wider application of formal and informal public education at the adult level by government and community bodies (Barnett, 1997; Brookfield, 2005). Both have taken a sociological approach to understanding critical thinking, and their published work frames my discussion. Similarly, Paul Ramsden in Australia has developed teaching strategies and approaches to encourage the student experience of learning (Ramsden, 2003). In addition, he advocates integration of content and teaching to the student's level and speed of uptake. He provides excellent strategies for student engagement, effective assessment of student understanding and evaluation of teaching practice. His work has greatly influenced teaching approaches and curricula at UNSW Medicine and so was useful contextual background.

These researchers are three of many who have examined student learning, and their work influenced my examination of conceptual learning more specifically, focussing on the process rather than the body of knowledge obtained. Other theorists, such as Entwistle

(2008) have reviewed conceptual learning, providing important insight into the thinking processes of students. In particular, Entwistle brought together theories around the key transition points and transformative nature of conceptual learning. By so doing, he suggested that students' thinking processes within these separate transition points are likely to be distinct from each other and also interconnected. Further, he proposed that when students learn about academic practice, they are more able to link up their learning approaches and learn knowledge concepts more easily. At the same time, students are unaware of this process and unlikely to actively observe the underlying stages or influences. It follows that understanding how students feel and what they experience at these difficult points is not easy. Therefore, the methods used to obtain data are an important focus of my research methodology.

Moving on to discuss learning processes necessarily involves discussing Perry's (1970) influential work on conceptions of knowledge that identified the key epistemological stages through which the learner progresses to develop higher level conceptual knowledge. Central to Perry's categorisation and stages of learning is the idea that, as learning occurs and academic knowledge is gained, students emerge from a dualist state to a relativistic one. This is usually a transformative step: a sense of becoming is described, as this is not just a stage of knowledge acquisition (Perry, 1970). A learner crossing this pivotal point is moving from an approach that takes knowledge at face value – it is either right or wrong, to being capable of increased objectiveness, clear evaluative skills and being able to explain and teach this knowledge, rather than just balance it up. However, this integration of experiences and knowledge is often "implicit," going unnoticed by the learner (Perry, 1970, p. 42). Perry's categories have been used widely across educational research and development, and the well-known SOLO Taxonomy was derived partly from this work by Biggs and Collis (1982). Indeed, the SOLO model has been used widely to examine student learning. For instance, there is high quality research to create and evaluate competencies in undergraduate science curricula in Denmark (Brabrand & Dahl, 2009), and for accounting disciplines (Lucas & Mladenovic, 2009).

Entwistle (2008) took this work further, combining three theoretical elements together into a new model. Using Perry's work on conceptions of knowledge, Säljö's work on conceptions of learning (Säljö, 1979; Säljö & Marton, 1997), and his own work on knowledge objects (Entwistle & Marton, 1994), Entwistle skillfully created a new schema of "developmental stages of conceptions of knowledge and learning" (Entwistle, 2008, p. 27). This model (see Figure 2.1 below) provided a useful framework for my early research.

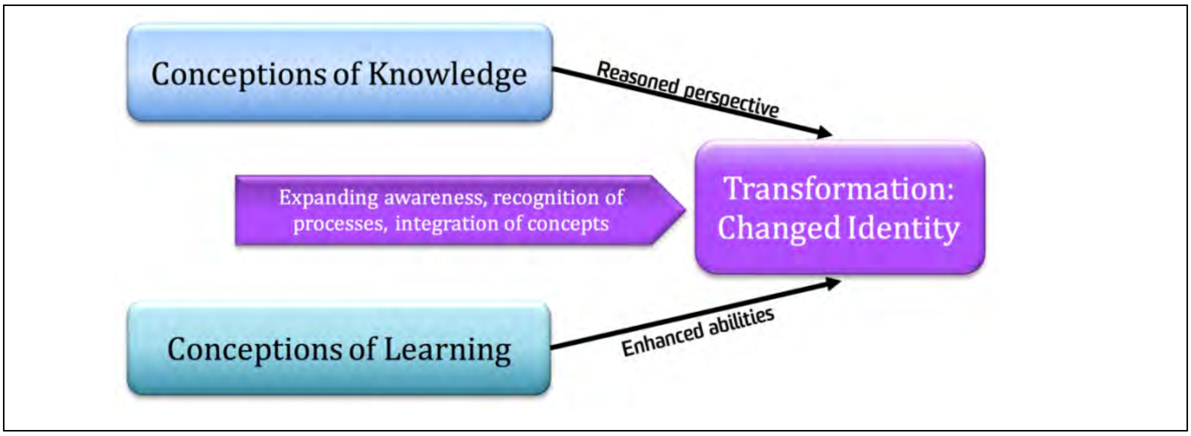

Figure 2.1 Developmental stages in conceptions of knowledge and learning (Based on Entwistle, 2008, p. 27)

This combination of knowledge, learning and object aspects of learning elements creates a useful model, echoing the idea of *episteme* which is a "system of ideas or way of understanding that allows us to establish knowledge of the concept" (Perkins 2006, p. 42). Entwistle's model provides a generic, developmental epistemic map of the progression of student learning. This starts with awareness in the more basic dualistic approach to crossing from a "pivotal position" or threshold to a more relativistic approach that is enabling and transformative (Entwistle, 2008, p. 21). This schema proposes that, as the student progresses from a dualistic knowledge base via a possible momentary stage of multiplicity to a stage of relativistic knowledge, their conceptual learning skills alter as well. Thus, Entwistle declares that that these could be acting synergistically in learning conceptual knowledge, as well as there being demonstrable change in conceptual or academic knowledge and academic conceptual learning skills. This is borne out in previous research of student learning of medical biostatistics (Quinnell et al., 2013). This schema inspired my main thesis question: What is happening in the liminal space in terms of critical thinking and conceptual learning? Further, it influenced the study design that focusses on hearing directly from students about what they feel and experience at this pivotal learning moment.

2.1.3 Factors Affecting Conceptual Learning

The educational developmental theories of the developmental psychologist contemporaries Jean Piaget (1896-1980) and Lev Semyonovich Vygotsky (1896-1934) are introduced here as key to educational theory. Piaget is acclaimed throughout education circles for his specific cognitive developmental stages that a child takes to reach an adult's level of intellect (Smith, 1997). As with the earlier educationist Dewey, this major contribution to child education derived from naturalistic observation of children at play and in the classroom, and from his psychometric analysis and psychiatric examination of children and adults (Piaget, 1952). Piaget placed a major emphasis on the child developing from egocentric to sociocentric implying that they had to develop first before they could learn as an adult (Bruner, 1997). Essentially, Piaget saw the learner as central to learning, leading to the cognitive-radical constructivist view of learning.

In contrast, Vygotsky believed that the social environment was central to the learning, becoming a major influence of the social-realist constructivist view of learning (Liu & Matthews, 2005). Vygotsky emphasised the social-mind perspective; his understanding of the world was based on the social world 'making meaning'. Vygotsky's view was that social learning comes prior to development: "learning is a necessary and universal aspect of the process of developing culturally organized, specifically human psychological function" (1978, p. 90). Vygotsky's theories have led to many effective educational strategies, including the "zone of proximal development" commonly known as the ZPD (Chaiklin, 2003, p. 40), which will be examined in more detail later.

2.1.4 The Transformative Learning Journey

According to Grabove (1997, p. 89), Mezirow believes that the "essence of adult education" is transformative learning via reflective practice. That said, Mezirow (1997) acknowledges that not all reflectivity leads to transformation, that not all transformation derives from reflection, and that reflection needs to be critical to be effective. In contrast, other theorists in educational research argue that critical thinking is more important in this learning process than mere reflection (Barnett, 2004; Garrison, 1991; Paul, 1993). However, these theorists appear to agree that transformation through conceptual learning is a key turning point for learners in the acquisition of disciplinary knowledge and eventual expertise, and that this is a unique journey for every individual (Land et al., 2010). Drawing these explanations together, transformative learning appears to involve self-reflection, leading to a significant shift in understanding that allows the learner to become more independent and change her beliefs and ways of thinking and practising.

Another main influence regarding transformative learning in education curricula is the experiential learning movement initiated by educational research on student learning in the 1970s and 1980s, which was refined and delineated by Kolb's (2015) model of student learning (originally published in 1984). This new approach induced substantive changes in curricular design and teaching approaches that remain in use today within healthcare education. Problem-based learning derived from this approach and developed as a specific methodology (Maudsley & Strivens, 2000), finding popularity within medical training (Allodola, 2014). Theoretically, the Kolb model rests upon a central concept that we adapt to social and physical environment by learning and that knowledge is continually created, revised and then recreated. In order to learn for transformative understanding, Kolb proposed that the learner needs to progress through four stages of experience. Firstly, a concrete experience (doing) followed by reflective observation (reviewing the experience) which initiates thinking of new ideas or modifies learner understanding of an existing abstract concept (abstract conceptualisation) (Kolb, 2015). This is followed by a testing of these new understandings within new situations (active experimentation). The emphasis on the reflective experience of the process was revolutionary at the time. Kolb's learning cycle and spiral model illustrate this approach (Kolb, 2015, p. 50,61) and have been adapted effectively within the Threshold Concept Framework (TCF) research to assist in explaining conceptual learning, for example by Kinchin and Miller (2012).

Transformative and reflective learning models have proved popular and effective in assisting student outcomes through curricular change and educational innovation. These successful approaches have been developed into newer models, such as team-based learning, as advocated by Michaelsen and the TBL Collaborative (Michaelsen, Davidson, & Major, 2014). This highly structured, large class teaching approach has been shown to improve student engagement and academic outcomes in nursing (e.g. Clark, Nguyen, Bray, & Levine, 2008) and medicine (e.g. Koles, Stolfi, Borges, Nelson, & Parmelee, 2010). Indeed, Espey (2018) demonstrated that this form of teaching can assist in development of student critical thinking skills. However, there are political and resource obstacles to effectively implementing this type of curricular activity within and across faculty and curricula (B. M. Thompson et al., 2007) and more evidence is needed to confirm if all students (especially those with poorer grades) benefit from this approach (Sisk, 2011).

Yet, despite research and innovation providing evidence from teaching practice, we are no closer to illuminating the individual learning journey of students. However, the disciplinary conceptual learning model of the TCF (Meyer & Land, 2003, 2005) has had some success in doing this. As defined in the introductory chapter, these concepts are significant disciplinary concepts that can be troublesome for student learning. In addition, they have an integrative effect on related concepts and are transformative, with both an epistemological and ontological impact (Meyer & Land, 2003, 2005). These threshold concepts can act as struggle points in student conceptual learning within academic disciplines and the TCF has proven useful in targeting these for educational development and improving student outcomes.

Disciplinary Threshold Concepts

Identifying and teaching to the threshold concepts within a discipline using these characteristics has shown some benefit to the learner, as these tend to be where students get stuck, frustrated and even come to a grinding halt in their learning (Entwistle, 2005, pp.5-9). Jan H.F (Erik) Meyer and Ray Land (2003, 2005) introduced the terminology and characteristics of threshold concepts within the disciplines, and further research has extended this idea, providing several practical frameworks for use by educators. Research following these well-received publications has concentrated on identifying disciplinary threshold concepts. This has proved straightforward in disciplines which consist of the hard sciences of mathematics and physics, but less easy in soft discipline areas, such as the arts, sociology, psychology, healthcare practice, biology (Collett, Neve, & Stephen, 2017), and certain aspects of research (Kiley & Wisker, 2009).

Since this initial interest in the identification of threshold concepts across the disciplines, research has moved onto the process of examining teaching and developing pedagogical support at these points with variable success (Barradell & Peseta, 2014). This is despite substantiated criticisms of the framework. Critics have targeted the misidentification of non-transformative or non-troublesome concepts as threshold concepts as a key problem. This issue appears to stem from the vagueness and lack of objectiveness in the original classification of threshold concept characteristics with poor methodology used in threshold concept identification and measurement of attainment (Nicola-Richmond, Pépin, Larkin, & Taylor, 2018). This has led to some concepts being judged as threshold when they are not transformative, troublesome or integrative to most students who encounter them (Rowbottom, 2007, p. 268; Barradell, 2013, p. 266). O'Donnell (2010, p. 1) was resoundingly critical of the identification of threshold concepts, arguing that there were "deep-seated conceptual problems" with the process as it then was, citing "impotent" characteristic criteria that are implemented with "elastic interpretations," making it difficult for disciplinary threshold concepts to be clearly identified. Furthermore, there has been concern that these threshold concepts are "agent-relative," as concepts are encountered and mastered differently by every individual (Rowbottom, 2007, p. 267).

Various disciplines have been outlined in terms of threshold knowledge concepts and lesser concepts, but there is some argument within disciplines about identification of key threshold concepts, for example, opportunity cost in economics has been disputed (O'Donnell, 2010). Furthermore, there are inter-disciplinary variations. For example, the concepts of timescale related to evolution in biology and geology was initially considered as a core threshold concept, but now specific terms such as *variation* are preferred and have been shown to be a more effective way of teaching the effect of time within evolution (Heddy & Sinatra, 2013). Similarly, in geology, time scale was originally identified as having threshold concept status. However, a recent teaching experiment struggled to show any improvement in geology students' understanding of evolution when deep time was taught as a teaching intervention compared to a control group of biology students (Nolan, 2018). This suggests that there are over-arching themes or ideas (such as evolution and timescale) that are made up of or relate to other relevant threshold concepts such as adaptation, variation, inheritance, and extinction.

These criticisms raise the question as to whether the original characteristics should all be met to be named a threshold concept, or if some should be considered more important. Initially these characteristics were not all deemed essential (Meyer & Land, 2005). Now, the major threshold concepts in a discipline are expected to have most of these characteristics, except that individual variation in the learning is acknowledged and celebrated (Meyer & Timmermans, 2016). Identification of disciplinary threshold concepts should be derived from information gathered from academics and teachers of different experience level and a fair cross-section of students (Meyer, 2016; J. A. Timmermans & Meyer, 2017). There is evidence that qualitative data sought directly from students and experts can provide better data than quantitative analysis of assessment outcomes, but this is acknowledged to be a more complex and arduous research approach (Barradell, 2013). In addition, according to Barradell (2013) those relevant to, but external to the learning process should be encouraged to take part in this identification process, including graduate professionals, experts in the practice field and the relevant community (e.g. patients in the health care context). She argues that these associated stakeholders have substantial prior knowledge and experience in the field as well as expectations regarding the standards and levels of competency within the practice. Where practicable, this seems a sensible approach that could add a wider perspective to the classification of threshold concepts and potentially improve the accuracy and usefulness of the research.

Further confusion has arisen around the identification of threshold concepts that on closer inspection could be more correctly labelled as *procedural* concepts. These are “doing” concepts or skills, rather than theoretical knowledge or “seeing” concepts (Rowbottom, 2007, p. 267). For example, there is growing evidence that suggests that learners require other transferable conceptual elements for successful learning of disciplinary threshold concepts. These inter-disciplinary elements have been identified, such as the literary concepts of ambiguity and context (Huq, Nichols, & Aryal, 2016), abstraction and mindfulness (Quinnell et al., 2013), and critical reflection (Howden, 2018). In addition, critical thinking appears necessary for tackling assumptions, the “loaded knowledge” of disciplines, and to critically examine the counterintuitive nature of new concepts (Ricketts, 2010, p. 47). Theories around learner dispositions and the transference of knowledge come to the fore here, as these can help to examine critical thinking both as a possible threshold concept or skill and as a facilitator of transformation (Perkins, Jay, & Tishman, 1993).

Critical thinking is one of the most commonly detected threshold procedural skills, for example, identified within information literacy (Blackmore, 2010; Townsend, Brunetti, & Hofer, 2011), academic literacy (Downs & Robertson, 2015; Hammer & Green, 2011), and evidence-based medicine (Martindale, 2015; Rudman, Gustavsson, Ehrenberg, Boström, & Wallin, 2012). This relates well to Entwistle’s (2008) model for developmental conceptual learning (Figure 2.1), as procedural learning runs parallel to and interacts with the conceptual learning process. Thus, threshold conceptual skills and threshold knowledge concepts run parallel in the conceptual learning moment and interact in a positive (synergistic) or negative (antagonistic) manner with the learning. As my thesis was to examine skills and knowledge learning in the liminal space, this layering of learner dispositions and Entwistle’s model onto the threshold concept framework was considered pertinent to my methodological approach and is investigated later.

The Learning Point: The Liminal Space

The nature of crossing the transformative threshold of a troublesome concept is described as inherently complex and difficult, often causing emotional issues and learning difficulties (Cousin, 2006b; Rattray, 2016). As introduced in Chapter 1, this process of gaining conceptual knowledge and transforming in terms of belief and academic approach is represented as the so-called 'liminal space'. The liminal space is used to signify the point where the learner gets stuck, confused, and challenged, and where she often has to unlearn concepts in order to move forward to a deeper or new understanding (Entwistle, 2003). In the threshold concept literature, this liminality is described in many different ways, for example Kabo and Baillie (2010, p. 308) found learner variation within the space, suggesting a "spectrum of liminality." Personally, I conceive this as a 3-dimensional egg-shaped ovoid space with multiple possible routes across from different entry points at the blunter end of the ovoid that head toward various exit points at the more pointed end. These personalized journeys traverse a variably viscous route that can hinder, deflect or ease the path forward to the other side. After many trials and tribulations, the learner crosses the space, the conceptual threshold, to higher understanding and transformed knowing (refer to Figure 1.1).

This process is thought to be time-dependent, although some learners traverse the liminal space quickly, others may never achieve the crossing of the threshold, becoming stuck in limbo without the necessary understanding or only a sub-liminal attainment. In addition, the learner often experiences an oscillation in understanding; one minute being able to 'grasp' the concept, and the next minute understanding slips away from them. This partial understanding can come and go and additionally learners can mimic understanding even if they have not got a full grasp it (Kabo & Baillie, 2010; Meyer & Land, 2005). Furthermore, crossing this liminal space can create severe emotional overtones for the learner, creating confusion, anxiety, fear and dislike of the topic (Land, Meyer, & Smith, 2008; Rattray, 2018). There are parallels here with the "epistemological shudder" characterised by confusion and perplexity experienced when there is an "obvious paradox or contradiction" to the learner's present understanding (Charteris, 2014, p. 106). Some of this affective response is attributed to the 'reconstitutive' nature of the transformative experience (see Figure 2.2. below). The learner often has to "reconfigure" her prior conceptual understandings and ways of seeing, in order to transform to a more advanced disciplinary way of knowing, seeing and being (Land & Rattray, 2017, p. 64).

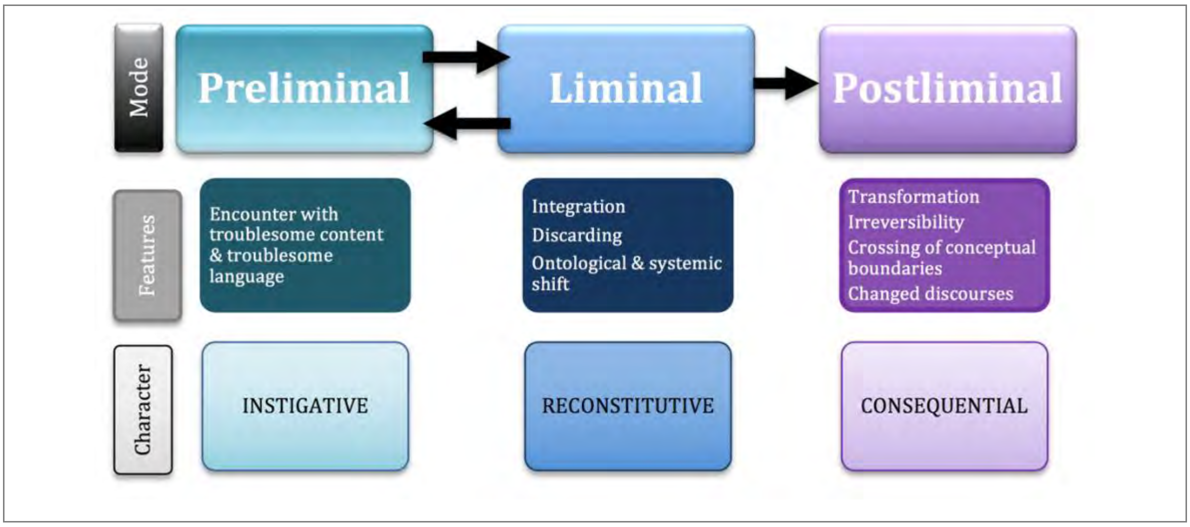

Figure 2.2 The reconstitutive nature of the learning journey across the liminal space (Based on Land, Cousin, Meyer & Davies, 2005; Land et al., 2010, p. xii)

According to this model, to cross a threshold concept the learner must traverse all three stages, acknowledging individual variations in how and when learners are able to achieve this (Land & Meyer, 2010). The pre-liminal stage is where and when the threshold "portal" is first noticed and may be different for each learner (Meyer & Land, 2005, p. 373). Arriving at this portal, the learner may not be able to recognise the threshold concept for what it is, either not noticing that it is a gateway to a new understanding or, alternatively, noticing it but turning away from it and taking a different path (Land & Meyer, 2010). The pre-liminal mode begins when the learner first meets conceptually troublesome content or language, engages with it, and prepares to enter the liminal space where reconstitutive learning occurs. This stage is characterised by *instigation* – a beginning of engagement, which is unsettling and "renders" understanding "fluid" (Land et al., 2010, p. xi). This preparatory phase appears to be essential for full engagement of the liminal mode to occur, where the hard work of the learning usually happens.

On entering the liminal stage, the learner begins to grapple with difficult concepts by extending their thinking beyond what she is comfortable with, jettisoning old concepts and reconstructing new understandings of her present knowledge, often by integrating new conceptual understanding with older conceptual understandings (Land et al., 2010). Another way of viewing this process is more accepting of this "reformulation" of the learner's conceptual frame and existing understandings (Schwartzman, 2010, p. 40), occasioning a "rupture of knowing" (Schwartzman, 2010, p. 21). This changes the learner's perception of the disciplinary subject; her eyes are opened to new ways of thinking and seeing (Land & Meyer, 2010). If this latter, transformative effect occurs, sometimes experienced as a metamorphosis, then she has crossed the threshold and is in the "consequential" post-liminal mode (Land et al., 2010, p. xi). She is now capable of taking part in discourse at a higher level of understanding and can go on, maybe tentatively at first, to understand more complex concepts. It has been mentioned that mental concentration and reflection are required for this reconstitutive transformative process (Schwartzman, 2010, p.40), but this has not been a major focus of research so far. This way of examining liminality depends on various inner characteristics such as dispositions and skills, as well as external (environmental and instructional) factors. Mälkki and Green (2014) have uncovered some aspects of focus and reflection within the pre-liminal and liminal states. Their approach used mapping of the micro-processes of transformation from the first-person point of view and detailed the discomfort confronting learners in the liminal space. This research offers useful pointers for the educator seeking to help learners on their learning journey.

In conclusion, the liminal space is a crucial learning space for disciplinary understanding and transformation and recent research has concentrated on the micro-processes that assist this. For instance, the 3rd and 4th Biennial International Threshold Concept Conferences (2008, 2010) specifically explored liminal space and transformation, initiating many related research studies, published papers and book chapters. Unfortunately, the inherently troublesome and idiosyncratic nature of the dynamic transitional learning zone of the liminal space is difficult to theorise, research and operationalise (Kabo & Baillie, 2010; J. A. Timmermans, 2010). Land and Myer (2010) emphasise the importance of understanding the dynamics of the liminal journey to enable better assessment of students' understanding and transformation. They suggest that researchers look to new ways of "mapping, representing and forming estimations" of this learning process across all the liminal states, especially the individual variation of this experience (Land & Meyer, 2010, pp. 76–77).

Conceptual Webs and Networks

Also important to this research is the notion of webs, networks and mapping of threshold and other concepts within the disciplines. Meyer and Land's framework (2003, 2005) provided a useful approach for identifying both discipline-specific knowledge concepts and the more generic (mainly research-based) procedural (skill-based) concepts. They later called threshold concepts the “jewels in the curriculum” and recommended that these be charted as “waypoints to be navigated” in the learning journey of the student (Land & Meyer, 2010, p. 75). A 2004-2007 project by Davies and Mangan at Staffordshire University[1] aimed to identify threshold concepts explicitly identified and mapped concepts in macroeconomics, microeconomics and international economics fields as shown in Figure 2.3 below. The project was productive with documented impact following embedding of economics threshold concepts into various curricula and introduction of specially designed activities to assist students’ learning. Despite later disagreement and remapping of early webs and disciplinary models, these have been useful in providing a basic curricular structure for teaching and learning disciplines, for example in Biology (Ross, Taylor, Hughes, Kofod, et al., 2010, pp. 171–172) and medical statistics (Quinnell & Thompson, 2010).

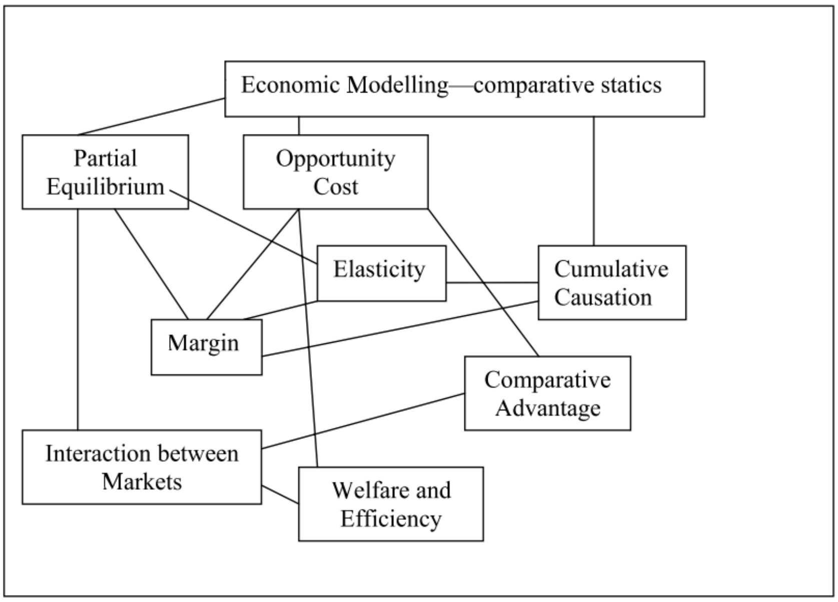

Figure 2.3 An early web of threshold concepts in Economics
(Source: Davies and Mangan, 2007, p. 722. Taylor & Francis Ltd: www.tandfonline.com)

New tools have been applied to identifying and investigating the links between threshold concepts. For example, Kinchin and colleagues (2014b; 2010) have encouraged concept mapping as an educational tool, pioneering its use for mapping threshold concepts. The visualisation of conceptual networks and webs has encouraged in-depth disciplinary discussions within and across academic communities about threshold concepts, regarding

[1] http://www.staffs.ac.uk/schools/business/iepr/etc/index.htm

how they link, integrate and are co-dependent. Furthermore, mapping these relationships has revealed a fundamental difference between expert practitioners' practice and the teaching of the procedural, systematised "chains of practice" and "networks of understanding" that outline the disciplinary knowledge and practice for the learner (Kinchin, Cabot, & Hay, 2008, p. 316). Mapping concepts has helped to reveal and clarify different types of threshold concepts and associated themes, ideas and ways of thinking in general and within disciplines. For example, researchers have posited "modelling concepts" (Davies & Mangan, 2010, p. 195), "overarching threshold concepts" (Quinnell & Thompson, 2010, p. 152), concept fusion (Tucker, Weedman, Bruce, & Edwards, 2014) and ways of thinking and practising (Barradell & Peseta, 2018; Martindale, 2015). This more recent research has gone a long way to support the identification and clarification of threshold concepts, conceptual networks and ways of thinking and practising. Nonetheless, more needs to be discovered about how these conceptual elements interrelate, especially regarding how learners integrate these for navigation of their disciplinary learning journey to expertise. This became the general aim of my first research question, discussed in detail in Chapter 4.

Constructing a Revised Threshold Concept Framework

As mentioned earlier, identifying, tracking and mapping these threshold concepts within the disciplines is proving difficult (Meyer, 2016). Thus, a more powerful theoretical lens is needed, coupled with a closer examination of the actual thinking processes that assist the learner through this conundrum of epistemic and ontological transformation (Entwistle, 2008; Land et al., 2014). Suggestions from Rountree, Robins and Rountree (2013, p. 284) provide further sophistication to the TCF as they propose a new threshold characteristic that recognises the importance of two other domains aside from knowledge, namely the employment of strategies for full threshold transformation resulting in the construction and internalisation by the learner of a "new range of mental models." Another approach called the Threshold Capability Integrated Theoretical Framework (TCITF) was put forward by Baillie, Bowden and Meyer (2013). This re-evaluated the TCF using the Capability Theory which is based on phenomenography and variation theory. This work introduced the term *threshold capabilities*, a term that links the idea of episteme with the Capability Theory. According to this theory as applied to the TCF, a threshold capability is the professional know-how that enables a learner to gain the *knowledge capability* that is the overall knowledge and ability that allows a professional to practice in real situations (Baillie et al., 2013, p. 236). Both approaches provide practical methods of analysis for conceptual learning and were applied at times within my research.

Another fresh methodological approach for the TCF, called the integrated threshold concept knowledge (ITCK), was initiated by Meyer & Timmermans (2016). This provided the next stage in threshold concepts exploration, having reframed the original approach to address issues and limitations that researchers have discovered during the previous decade. Their concerns were mainly related to the over-simplifications in the analysis of the threshold concept journey, including concerns that individual variation in learning needed to be researched and also included in design of teaching resources. For example, the TCF tends to map the liminal journey as linear, when for many individual learners it is far more tortuous (Meyer, 2016, p. 467). Hence, the focus of the ITCK research approach returns to the affective, cognitive, epistemic and ontological elements within the liminal space, allowing a more realistic insight into individual liminal journeys that can account better for the variability in cognitive and metacognitive processes (J. A. Timmermans & Meyer, 2017). In addition, their approach is directly student-centred rather than overtly teacher or expert-centred, and the focus is more clearly on using qualitative methodologies to explore where students are getting stuck, with the reasoning that this is a more powerful research technique (Meyer & Timmermans, 2016). The implication and application of these re-evaluations and additions to the TCF framework are used in this thesis, as outlined in Chapter 3.

2.1.5 Conceptual Learning in Context

Key to this thesis is the context: the discipline of Quality of Medical Practice. Statistics has been well-researched in the past regarding conceptual learning, and, since I began my research, there has been a commensurate growth in published and thesis literature on threshold concepts in EBP in specific health professions (e.g. nursing, physiotherapy, and occupational therapy). Further, there has been an expansion of research around academic writing, including two recent books, themed conferences and establishment of international research collaborations. This examination of academic writing has initiated additional research into academic research skills, including information literacy, which is an important element of evidence-based practice (Desanto & Harrington, 2017).

So far, there has been less investigation of specific threshold concepts in biostatistics and epidemiology. It is not clear why this is so, but these subjects are acknowledged as conceptually difficult even for the experts. For instance, Wills (2017) interviewed staff and students on the difficulties that they encountered in learning and understanding statistics. Twelve of the 13 staff had a statistical background, the other an epidemiological background. Despite their expertise, he found that from a list of key statistical concepts that "you found most difficult to learn and understand," 5 out of 13 experts found the central limit theorem difficult, and 4 out of 13 found power, bias and precision, and conditional probability difficult (Wills, 2017, pp. 436–437). He also found that concepts appeared to overlap as if they were not entirely separate, naming three "underlying themes" and understandings that link these: 1. *Statistical inference, including the ideas of uncertainty and sampling variation*; 2. *Basic probability*; and 3. *Describing and visualising data* (ranked from highest to lowest evidence in support of the claims) (Wills, 2017, p. 440). As with Barradell and Peseta's (2018) understanding of thematic ideas and Tucker's (2016) idea of concept fusion, Wells considers that these themes can assist in the learning and integration of key related threshold concepts. In contrast to Barradell & Peseta (2018) but in agreement with Tucker (2016), he considers that these themes can be partially threshold concept in their own right, causing the troublesome nature and difficulties experienced by staff and students shown by his data.

Prior to my data collection year, there was no identification of threshold concepts and how they systematise in EBP in medicine, apart from my own research (Quinnell & Thompson, 2010; R. Thompson, 2008). In contrast, EBP in nursing had been researched in more depth for threshold concepts (Martindale, 2015), the teaching of conceptual learning (Johnston & Fineout-Overholt, 2006) and implementation of EBP into nursing practice (Rudman et al., 2012). Therefore, there was a clear argument at the beginning of my thesis, for the first research question: the investigation of these EBP and medical biostatistics threshold concepts in undergraduate medicine. Also, identifying these concepts and their relationships was seen vital for providing a basis for the analysis and investigation of the interview data collected. The available research on EBP, and medical biostatistical concepts at the time was evaluated according to the strength of evidence and summarised in Appendix 2.1, to provide a clear starting point for first thesis research question. Chapter 4 develops and utilises this evidence within the analysis and reports on new ways of conceiving conceptual elements in EBP and medical biostatistics.

2.2 THE SKILL: CRITICAL THINKING

The previous section discussed the main literature on conceptual learning from a broad base to the specific subjects that this thesis investigates. This section moves on to examine the main research inquiry, the intersection of critical thinking with conceptual learning. Critical thinking appears important in the process of learning, but less is understood of the means by which it stimulates conceptual learning, the gaining of knowledge and transformation. To the casual observer, critical thinking appears to be definable and straightforward, with a general consensus of critical thinking as a key group of skills that can be taught and can be learned. However, this rather simple, narrow view of critical thinking is challenged by the literature, as discussed below.

2.2.1 What is Critical Thinking?

Thinking about thinking could claim to one of the luxury past-times of the philosophising human race and has demanded the attention of our greatest philosophers. Indeed, the nature of "good" as compared to "bad thinking" (Dewey, 1910f, p. 13) has been pondered on and deliberated on by some of our greatest thinkers, across the world, within and across cultures, as far back in time as we have records. Contributors since ancient times have written works on critical thinking, creating waves of illumination, led by philosophers and educators such as Socrates, Plato, Aristotle, Gautama Buddha, Confucius, Francis Bacon, René Descartes, John Locke, GWF Hegel, John Dewey and Bertrand Russell. Unfortunately, this thesis cannot examine all these influences but will concentrate on philosophical and educational perspectives of more recent times.

From Dewey to the 1950s

Over the past century or more there have been several smaller waves of research focusing on good thinking and thinking dispositions, which contrasts but is closely related to research on critical thinking skills and abilities. Dewey's seminal work on thinking and education, *How We Think* (1910b) took a philosophical approach and produced a practical guide on how to teach children to develop their thinking ability. Behind this work lay two crucial ideas. Firstly, that the child entering school did not arrive as 'tabula rasa', a blank slate that the society of the day expected teachers to write society's prerequisite knowledge upon. Dewey (1900, p. 70) considered that children brought their own experiences and knowledge to the classroom and that "life experiences" continued to be important throughout their learning. Secondly, he concluded that a child's effort is at its best when trying to gain knowledge, and that problem-solving was one way that could help children learn knowledge. Active learning was the key; by putting new learning to use in solving problems, the student could master concepts better. Dewey (1910d) proposed that this is how children assimilate new learning and can "react without thinking" (p. 223). Moreover, he thought that knowledge is continually transformed and integrated into the child's mind to be of use in further learning of new concepts. He said that there "is no end to this spiral process: foreign subject-matter transformed through thinking into a familiar possession becomes a resource for judging and assimilating additional foreign subject-matter" (Dewey, 1910d, p. 223).

Interestingly, Dewey gave keen descriptions of the uncomfortable states that reflective thinking provokes in the learner. He proposed that this uncertainness elicits the learner to think and seek information to resolve doubt and thence solve the problem (Dewey, 1910c). He contended that underlying doubting approaches were necessary to think well, including a need to be in a state of "mental uneasiness" as this helps to "maintain the state of doubt and to carry on systematic and protracted inquiry" (Dewey, 1910f, p. 13). Dewey's child-centred theories of education depended on his belief that each of us has (what would later be called) dispositions that are key to our understanding of the world and how we approach thinking and learning. He wrote of experience, foreknowledge and self-interest that the individual brings to our thinking and learning. Discussing eminent historical thinkers such as Bacon and Locke, he concluded that education is not just to "safeguard an individual against the besetting erroneous tendencies of his own mind" but, at the same time, should "undermine and destroy" current and past "prejudices" (Dewey, 1910e, p. 23). He pointedly positions the education of individuals as a means of social change and improvement.

How we Think (Dewey, 1910b) focussed on how to train children to think, developing theories that placed an emphasis on the socio-cultural context of the learner. This seems sensible now but was controversial at the time. It is debatable how much his work stimulated changes in education systems during the twentieth century, but it changed education profoundly in terms of teaching approaches to student learning. However, there was little progress on examining thinking dispositions further until after World War II, when a further wave of research is seen. At this point in time in education, the promotion of "good thinking" became de rigueur and understanding how we reason and cogitate became fashionable in education. Dewey's work was essential to this movement, as it led to new debate and philosophical research that stimulated investigation of the cognitive psychology aspects of thinking. Maturing from the late 1950s through to the 1990s and resurfacing again today with the advance of new imaging technologies, psychological research into cognition of thinking and reasoning gave a boost to the parallel educational research. In reviewing the literature of this time, well established names such as Barnett, Biggs, Brookfield, Ennis, Entwistle, Jarvis, Moon, Mezirow, Norris, Paul, Perkins and Siegel arise.

Critical Thinking Emerges Beyond the 1940s

The critical thinking research literature developed from the 1950s onwards with educationalists taking a more theoretical, self-reflective perspective. Others, such as Bourdieu, a Marxist taking a philosophical approach, challenged the prevailing culture in other directions. An overview of this research provides useful theories for my purpose. Contributions accelerate after 1950 resulting with a major paroxysm of research published around 1980-1995. Mostly, these writers agree on critical thinking being a form of high-level thinking: intellectually disciplined, clear, purposeful, skilful, evidence-based, reflective, and fair. However, not all perceive critical thinking as a mere skill or even a complex group of skills, some prefer to classify it as more than this, as a *disposition* (a behavioural tendency) or even a *way of being*. This final idea of a holistic critical thinker is not new but is important with respect to the subjects of this thesis, the students. This idea has been developed by some of the greatest educational thinkers of the past 30 years, including Paul, Barnett and Brookfield. In North America, The Foundation for Critical Thinking, Richard Paul's legacy, has been dominant. This movement led to the establishment of a Paulian tradition and Paulian critical thinking, which emphasises three functions of thinking, the analytic, evaluative and creative (Paul & Elder, 2014). These influential thinkers are referred to later, as relevant to the thesis.

Critical Thinking through a Sociological Lens

Barnett (1997) and Brookfield (2005), among others, have examined critical thinking in higher education using a Marxist-social theory perspective. Separately, they suggested that the development of critical thinking is a powerful ability with which an individual can influence the world beyond; contending that higher education should be emancipatory. In parallel, they agreed that teaching critical thinking skills produces professionals capable of working within a fixed environment with a proficient level of professional aptitude but saw this is a confined approach. Independently, they proposed an ideal of nurturing students who become graduates capable of critical thought within a discipline and, at the same time, who were able and willing to critique their profession and society. This, they argued, will not only benefit the individual, but also society and the world. This built upon the "critical spirit" espoused by Siegel (1988, p. 39), comprising attitudes, thinking dispositions, habits and character traits that are essential for rationality and action related to critical thought as reasoning.

This discussion point provokes interesting questions about the purpose of higher education, especially as applied to the vocational discipline of medicine. Does a standard medical degree program produce an early stage professional capable of merely applying their newly gained skills to an environment (i.e. health care) but bereft of the ability to transfer these skills to other communities or life situations? What are the university and the Australian Medical Board's expectations for these graduates? Have we lost sight of the holistic nature of students, as people who live and can potentially interact within various communities and across many societal levels, and not just within the medical field? Does the processing of these students into accredited graduates with certain skills and instilled with certain attitudes, make them lose something of their critical spirit? From this questioning approach, more focussed issues arise regarding the possibilities for medical education, including whether its aim should be to create more rounded individuals who can function in an extended critical way, to be capable of theorising and critiquing many areas within and beyond their customary practice. Perhaps they should become critical practitioners rather than just graduates capable of medical internship (Barnett, 1997). This is relevant to my thesis, and I aimed to find a better way to develop medical students' critical thinking to enhance their potential within society as well as for the individual.

If critical thinking underpins the key decisions and actions of practice as graduates of university and medical school, then the learner's understanding of theories and skills that guide practice, such as abstraction is an essential step to facilitate the link between theory and practice (Baer, 2019). However, the complexity of both the learning environment and the wider world hinders the teaching this. Many have striven to define the *critical thinker* and the skills and abilities of critical thinking, but this needs to be explored further in order to illuminate the thinking process within the liminal space in order to aid the transformation to expert practice.

2.2.2 Perspectives on Critical Thinking

Since humans began to cast their thoughts beyond the demands of daily living they have been thinking about thinking. The influence of the ancient philosophers still resonates today in terms of logics and reasoning, rational thought and ethics, mathematical explanation and discourse. Similarly, religious and political philosophy across the ages and from many different perspectives, including Islam, Judaism, Christianity, Hinduism, Buddhism, Socialism and Marxism, has framed the ways in which communities have taught their children and directed adult learning in terms of thinking, freedom and self. Thus, philosophy has drawn us a bigger picture, highlighting the influence of history as well as the societies, nationalities and cultures of today. Critical thinking is inherent within all societies and cultures acting as an enabler, a facilitator and an activator to many things. However, we critical thinking is thwarted by some of society's chief elements: culture, religion, gender issues and politics. Similarly, conceptual learning as part of knowledge development has been examined through many perspectives across the ages. The idea that knowledge is power has added impetus to the need to understand how we learn concepts and take useful action in the world by transforming through learning. This implies that critical thinking and conceptual learning cannot be examined in isolation, so for my research, I examined them both separately and together, paying attention to the environment and power structures that surround and influence the research setting.

The Philosophical Perspective

Philosophers contemplate thinking often as it is one of the central elements of human activity and defining of our place in the world. Ennis' (1991, p. 8) characterisation of the "ideal critical thinker" produced clear descriptions of the elements that he thought characterise the critical thinker, listing twelve dispositions and sixteen abilities. He developed these criteria from personal experiences when he had found that critical thinking was paramount, including his involvement as a juror in a murder trial. This rather unique development process is evident from the content and depth of the descriptions provided, however this stimulus limited the type of dispositions and abilities he discussed, for instance there are few creative elements included, and the list is heavily based on logical decision-making, especially the itemised abilities. Despite this, these twelve dispositions capture the essence of critical attitude, and the sixteen abilities cover a comprehensive breadth of critical capacities. The reader can imagine that if all of these were combined in one individual, this person would be capable of crisp critical thought and critical action. Other weaknesses include a lack of description regarding connections and relationships between the dispositions and abilities, and a dearth of explanation on the incentives behind critical thought and the resultant action. Yet, Ennis' philosophical approach has successfully categorised key features of the critical thinker and these criteria and descriptions have been successfully developed into theories and strategies for educational development across the disciplines and the world.

Around the same time, another philosophical achievement was achieved in the categorisation of critical thinking using a Delphi method consensus by a panel of 46 educationists, scholars and leading critical thinking theorists (including Ennis and Paul) (Facione, 1990). This consensus, published by the American Philosophical Association, listed specific cognitive skills for critical thinking (6 core skills: inference, explanation, evaluation, self-regulation, interpretation, analysis; with 16 sub-skills). The panel provided a definition of the dispositions of a good critical thinker and examined the affective dispositions for this within two approaches: 1) approaches to life and living in general; and 2) approaches to specific issues, questions or problems. The consensus provided clear recommendations for the instruction and assessment of critical thinking and continues to be used, discussed and built upon within philosophical and educational circles and research. Interestingly, the panel agreed that the critical thinker needs a critical spirit integrated with implementation of the critical thinking skills (Facione, 1990, p. 11). Siegel's (2005) philosophical arguments for the existence of the critical spirit emphasised that the reasoning component of critical thinking may require the critical spirit for rational action to happen. From a philosophical point of view categorising critical thinking into specific skills criteria dismantles the integrity of critical thought. Thinking is a dynamic process, so to understand it fully, it is necessary to see it in action and hear the running commentary of the mind telling us what is going on. As discussed in detail in Chapter 3, this consideration led to a choice of methodological approach that sought a more holistic observation of the critical thinking process happening in the liminal space.

Another philosophical-educational viewpoint worthy of discussion is the notion of *ignorance*, the antithesis of my research topic. Dewey (1910c, p. 9) talked of "uncertainty" and "doubt" being key to stimulating thought but ignorance itself seems to have been ignored or overlooked by many educators. Its negative connotation, as the inverse of knowledge and its rather emotional overtones, may have contributed to this apparent slight.

Knowledge is still held as one of golden attainments in education; ignorance is the opposite and is seen as poor understanding and witlessness. Despite this, some educationalists and philosophers have chosen to embrace the idea of ignorance, not to the exclusion of teaching content knowledge but as an adjunct to enable its attainment. This is not meant to be "negative pedagogy" (B. Johnson, 1982, p. 165), the teaching of a student what not to know, but does touch on the subversive idea that teaching essentially directs students towards knowledge that society wishes them to know by avoiding exposure to certain undesirable knowledge. Johnson (1982) teasingly argues that there is a possibility that this is what pedagogy is: "Could it be that the pedagogical enterprise as such is always constitutively a project of teaching ignorance? … Does the educational system exist in order to promulgate knowledge, or is its main function rather to universalize a society's tacit agreement about what it has decided it does not and cannot know?" (p. 173).

In contrast, the ignorance that is more positively taught and has relevance to my research, is the learning of how to comprehend what we don't know and thence illuminating what we are attempting to learn. Witte, Kerwin and Witte (1998) embrace ignorance as essential, seeing it as a 'germ' that stimulates and energises learning. They challenge the age-long Western philosophy of knowledge and ignorance being "polar opposites. Knowledge is glory and ignorance or non-knowledge the enemy" and argue instead that ignorance should be recognised as symbiotic with learning knowledge and searching for enlightenment (Witte, Kerwin, & Witte, 1998, p.127). In addition, it is dynamic, altering with the acquirement of knowledge; true experts admit to more ignorance of a subject, the more that they understand it. Ignorance, in turn, stimulates further research and learning (Witte et al., 1998).

Some protagonists have progressed as far as to develop the concept of ignorance as an educational element that can be taught. To stimulate student learning and understanding, Arizona Medical School embraced ignorance into its curriculum decades ago (Witte, Kerwin, Witte, & Scadron, 1989) and still offers seminars and clinics on 'medical ignorance' where students are taught specifically to question where they detect gaps in their knowledge (University of Arizona Health Sciences Center, 2017). This approach is interesting, as the concept of ignorance overlaps and interacts with the concept and application of critical thinking. The idea of uncertainty and the unknown stimulating questioning is at the root of critical thinking; without this stimulus, why would we bother to learn more? Also, as many others have pointed out, a lack of knowledge can hinder our ability to be critical: "one can be a master of critical thinking skills, but without knowledge those skills won't do you much good" (Carroll, 2000, p.12). So, understanding ignorance may be very useful in understanding critical thinking, and this was investigated further in the thesis.

Together these examples of the philosophical perspective show how researchers of critical thinking come from diverse disciplines but frequently use a philosophical approach to tackle the complex matter of critical thinking.

The Psychological Perspective

It is generally accepted that we are far from understanding how our brain thinks, let alone how it thinks critically, creatively, reflectively, or conversely, poorly or haphazardly. Hence, the psychological perspective plays a very important part in the underlying knowledge of this aspect of critical thinking. Furthermore, advances in medicine are now able to take a closer look at the minuscule level of neuroscience and synapses. Key to the usefulness of this perspective is that it can take a microscopic look at thinking, at the level of cognitive processing and attempt to interpret this in a macroscopic, functional way. However, examining the larger scale theories on basic cognition, the processing of reasoned thought is not well understood even now. Fortunately, there are cognitive psychology models and theories that can help to understand the underlying processes involved. For critical thinking these models are useful for: rational, logical thought, the cognitive processes, and applied thinking. Also, cognitive psychology directly links with the philosophical ideas of learner dispositions and the importance of transference of skills for learning within and across the disciplines. Further detail on elements of cognitive psychology within these specific areas of interest is discussed in the relevant sections, including metacognition and higher thinking processes which are considered more fully in the analysis-discussion chapters.

The Educational (Psychology) Perspective

In general, educational theorists and teachers take the best, most relevant and useful research from varied perspectives and often blend these together to tackle the issues that are troubling their practice. Therefore, the terms used in educational literature reflect this, suggesting that developmental psychology approaches, sociological ideas, and theoretical discussion feed into the educational research thinking. However, one specific concept dominates previous research here: thinking dispositions. These have been researched by educationists to explain many educational phenomena. These include how to achieve student outcomes, how to develop clear achievable objectives, how to teach skills and practice, how to develop and attain attributes and capabilities, and, most recently, for identification of and teaching to threshold concepts. Critical thinking is a core part of learning and developing into adulthood, so accessing the information that attempts to unravel how we learn and develop, should shine further light onto critical thinking. As introduced earlier, Piaget and Vygotsky led the research along educational psychology lines into conceptual learning, and this is examined in more depth subsequently specifically with regard to critical thinking. First, however, it is worth focusing on the key educational research theory of thinking dispositions and how this relates to critical thinking in conceptual understanding.

Thinking Dispositions

In examining critical thinking for education, a cognitive psychology viewpoint is helpful. In introducing *triadic dispositions* Perkins, Jay and Tishman (1993) based their theory firmly upon basic cognitive psychology research on the processes that link intelligence and its output (Halpern, 2013). However, this is not a pure cognitive psychology approach as it included key socio-cultural factors in the process. Regarding critical thinking, there are three main elements of a general cognitive psychology approach that are useful for research. The first is that cognitive psychologists discuss critical thinking as being a 'higher order' of thinking. This level of thinking takes effort, involves complex thought, has lots of possible solutions and involves skills of judgement and a reasoned approach (Biggs, 1996; Bloom & Krathwohl, 1956). This element is used by many educationalists and is touched on by Perkins and his colleagues (1993) in their development of the triadic disposition theory. Secondly, Perkins and Salomon (1992, 2001) develop the idea of *transferability*, as introduced by Bourdieu (1977), in his idea of transposable dispositions. They argue that higher order skills need more reflection and sensitivity to enable effective transfer of the skill from one context (i.e. discipline) to another, and this concept was essential in my investigation. The third element is that of developmental psychology, which has transposed well into educational research. Many frameworks have been developed that enable the understanding of critical thinking, thinking and processing using this last element. For example, there are: Bloom's Taxonomy (Bloom & Krathwohl, 1956), Biggs' SOLO taxonomy (1996), Halpern's models of generic skills (2013), and Moseley, Baumfield, Elliot et al's (2004) extensive work on developing a framework for critical skills that encompasses information gathering, building understanding and productive thinking. Thus, these three elements have relevance to my research in terms of developing the theoretical framework to examine the thinking at the conceptual interface.

Returning to the concept of triadic dispositions (Perkins et al., 1993), this neatly brings together the elements mentioned above. Essentially, dispositions are one's ability to do something, but, at the same time they are more than this. For instance, teachers often see that a student has an ability, but she doesn't use it at the right moment or bother to use it when she could. The idea of triadic dispositions, theorises that to use an ability, a student must have both the *inclination* to do something and the *sensitivity* to notice when to use this ability (Perkins et al., 1993, p. 8). These inclinations are the urges, impulses, drives, tendencies, leanings, and desires that provoke us to do something. But the student also needs the sensitivity to realise when to use an ability. This is the alertness and awareness of a situation that enables a student to recognise when or when not to act with the final element of their disposition, their abilities: the skills to do, review, analyse, and decide. Perkins and colleagues (1993, p. 8) presented seven thinking dispositions that summarise critical thinking.

Good thinking is characterised as reflecting seven broad thinking dispositions, a disposition: to be broad and adventurous; toward sustained intellectual curiosity; to clarify and seek understanding; to be planful and strategic; to be intellectually careful; to seek and evaluate reasons; and to be metacognitive. These dispositions are consistent with those presented by other authors looking at the fundamental thinking responsible for critical ability (Barnett, 1997; Ennis, Baron, & Sternberg, 1987; Moseley et al., 2004). However, the triadic model stresses an extra dimension, the importance of the active employment of this thinking. As shown previously, others have argued that there is more to thinking disposition than just the ability, but in general they postulate these other factors as sitting outside of the disposition and working with it or against it to enable critical thinking. For instance, Siegel's (1988, p. 39) critical spirit appears separate to the actual thinking. So, Perkins, Jay and Tishman (1993) were breaking new ground by theorising that the inclination to use the skill and the sensitivity to understand when to use it, are part of the disposition itself.

In principle, this triadic disposition model adds a further dimension to Ennis' (1991) 'Characterization of the Ideal Critical Thinker'. Also, in applying this model to my research question, triadic dispositions appear just as applicable to discipline specific contexts as to general approaches to thinking and also useful for educational research. As argued by Siegel (1999), they are generalisable and therefore can be used in different contexts. Also, this theory appears flexible and adaptable to different contexts, fitting well with the Theory of Mind, incremental learning, Vygotsky's Zone of Proximal Development, sociocultural theorists and educationalist research. Moreover, it explains one of the most perplexing of circumstances in teaching when students are taught new abilities quite easily, but most students must be taught precisely how and when to use them, and then directed further as to how to use them in other situations.

In summary, the triadic dispositions model (Perkins et al., 1993) provides a careful exposition of reasoning as to why, logically, these steps to critical thinking occur, making this is one of the most convincing papers on this topic. This model is not overtly challenged within the literature and fits well within my discipline context and medical practice. Transferability of skills (Perkins & Salomon, 2001) and proactivity (Perkins, 2008) were introduced later. The proactivity concept has convergence with other theories and will be explored more fully later. Regarding the transferability of skills, Perkins and Salomon (2001) examine abilities and dispositions that aid in transferring other skills across disciplines, which also has relevance to this research.

2.2.3 The Critical Being

The work of Dewey, Ennis, Seigel, Perkins and his colleagues, and others has led to the emphasis on developing the whole critical practitioner, the critical spirit (Siegel, 1988, p. 39), or Barnett's critical being (1997, p. 63). This appears a fundamental but lofty learning objective for students and teachers within higher education. It resonates across the disciplines whose main aim (in more recent times) has been to teach the student to become, or at least aspire to become, an expert in the field. In medicine this is relevant considering the vocational calling, the context of medical practice and the bounded nature of the profession.

Barnett (1997) investigates critical thinking in this context using dispositions: "Critical reason calls for a disposition on the part of the individual to be critical" (p. 22). With this statement he concludes that individuals have to "assert themselves and constitute themselves" so that in being critical and asserting reason in the academic arena, students will need carry out "brave acts" (Barnett, 1997, p. 22). By this Barnett asserts that critical thinking is more than just cognitive but is experiential and holistic. He takes this further by examining the cultural context and suggesting students should be capable of a critical disposition which is deep-seated, can respond across many domains, and enables students to “size up the world in its different manifestations and the capacity to respond in different ways” (Barnett, 1997, p. 87). He then takes this into the realm of practice, as he believes that the critical spirit involves the whole person in all their interactions with the world. His concept of a critical being or critical spirit has parallels with Bourdieu’s habitus (1977) and triadic dispositions (Perkins et al., 1993). Fostering the graduate critical practitioner is Barnett’s aim, and my aim is to uncover what makes one, so his work greatly influenced my approach to this thesis. His critical being (see Figure 2.4) contains three core domains of knowledge, self and world (Barnett, 1997, p. 104). Unsurprisingly, his ideal graduate is a global citizen who is “enriching and practically oriented.”

Critical reason

- Knowledge
- The informal logic or skills
- What we often mean by critical thinking: the skills and dispositions
- Corresponds to *tendencies* of Perkins et al's triadic dispositions (1993)
- The most measurable domain, but complex and measures often don't capture the reality
- Not seen as creative

Critical Self-reflection

- The Self
- Corresponds to the *sensitivities* of Perkins et al's triadic dispositions (1993)
- Equates to the individual agency of habitus

Critical action

- The World
- The 'doing' element
- Corresponds to the *intentions* of Perkins et al's triadic dispositions (1993)
- This is what takes the individual to the higher level of emancipatory epistemology.

Figure 2.4 Barnett's Model of a Critical Being with explanations of the three domains (Barnett, R., Higher Education: A Critical Business © 1997, pp. 103–105. Reproduced with the kind permission of Open International Publishing Ltd. All rights reserved)

Barnett's critical being relates well to Perkins' (2008) later continuance of the idea of triadic dispositions and learning, where *possession of knowledge* is the basic level of understanding, i.e. what you have learned in terms of knowledge as currency or "money in the bank" (p. 4). Money in the bank is important, but not very exciting. *Performative knowledge*, on the other hand, is the idea of how this knowledge is used – i.e. how the dollars are spent (Perkins, 2008, p. 4). You need to have it to spend it, but how you spend it is important as well – it is best to use this knowledge wisely rather than squander it. These two levels equate well with Perry's (1970) epistemological levels of development in term of their understanding and use of knowledge (the SOLO taxonomy). On the other hand, *pro-active knowledge* is the highest level where the student is capable of much more – i.e. the student is now more flexible and can predict and connect using the knowledge, investing and spending wisely, creatively and with a personal, reasoned perspective. Again, this connects well to Perry's SOLO taxonomy, and, also, this final level of deep understanding and reasoned use of knowledge is where Perkins and Barnett ideas collide and cooperate: the critical being is proactive. The critical being should have perfect alignment of her abilities, intentions and sensibilities as shown by Figure 2.4 above. The critical being, proactivity and triadic dispositions cooperate well together and will be revisited later in the thesis.

Returning to the critical being, Barnett (1997, p. 103) created a curriculum that was based on development of a model for the categorisations of learning required to become a critical being. This framework addresses his three domains and brings in detail from his analysis of the levels of criticality required for a person to develop beyond a capability in the basic level of critical thinking skills. So, to be capable of "transformatory critique" across those three domains, is to be a critical being (Barnett, 1997, p. 103). The emphasis in this model is on the terms of learning for the student, including reflexivity, challenging knowledge and understanding and a reflective critique of society and the world. The domains of critical reason (i.e. knowledge) and critical self-reflection (i.e. self) align well with Ennis, Perkins et al, Kolb and others, with the "self" acting with key importance in critical reflection. Yet, what makes this model unique is Barnett's argument for including the "world" (1997, p. 89), as this domain is essential for graduates entering work and life within the widest possible society. If this critical being is the perfect graduate as Barnett suggests, it is important to understand the individual within this model, so the next section introduces the individual's experience of conceptual learning.

2.2.4 Critical Thinking in the Liminal Space

Critical thinking appears to be an inherent element of the troublesome and metacognitive nature of the threshold concept as defined by Meyer and Land (2003, 2005). Entwistle (2008) cautiously showed that in the development of conceptions of knowledge there is a parallel development of conceptions of learning (see Figure 2.1). Acquisition and memorisation of factual information, its analysis and deployment are skills that reproduce current knowledge in the early developmental stage of this model. To be effective for higher learning outcomes, these require critical thinking skills such as appraisal of current and newly found knowledge, research information and evidence. Additionally, Entwistle's model recommends a critical thinking dispositional approach in terms of application. This is supported by the research discussed in the previous section. In the "seeking meaning stage" that follows the pivotal point of transformation within the model (Entwistle, 2008, pp. 25–29), the student necessarily takes on higher-level critical and reflective thinking approaches in order to understand what has been learned and to realise that she can now see things in a different way. This model implies that critical thinking, reflective practice and other procedural concepts are acting as an essential transformative and integrative capacity within the learning process of conceptual learning. Thus, critical thinking is expected to act within the threshold concept liminal space.

Certainly, there is some evidence from the TCF to support the assertion that critical thinking is an inherent element of the liminal process, but this is often a residual finding, rather than the focus of the study, leaving many questions unanswered. For instance, a study by Berg, Erichsen and Hokstad (2016) examining the learning strategies of business students revealed the positive impact that deep learning in tackling threshold concepts had on student outcomes compared to a surface learning approach. However, this research did not take a closer look at the role of criticality within these strategies, to see how the deep learning improves outcomes beyond engagement and motivation.

More often critical thinking has been identified as a transformative process itself and has been considered more thoroughly in this role. Where critical thinking or critical reflexivity as a practice has been examined directly, critical thinking is considered and determined to be a threshold concept in its own right (Alnajjar & Altamimi, 2016). Indeed, several research groups examining the threshold concepts in information literacy and evidence-based practice have demonstrated that critical thinking is a threshold and transformative itself, even if it is being used for learning other concepts. For example, Martindale (2015) found that critical appraisal as a specific critical process in evidence-based practice meets the key characteristics of being transformative, troublesome, integrative, and bounded, although no comment was made on irreversibility. However, at the same time she recognised that this process was linked to critical thinking within the nursing practice, concurring with previous research by Rudman et al (2012).

A critical approach was described as essential to searching and more generally to information literacy skills by several early researchers on this topic (e.g. Blackmore, 2010; Townsend et al., 2011), and critical evaluation has been identified as a part of an information research threshold concept (Yorke-Barber, Atkinson, Possin, & Woodall, 2008). Similar findings have come from the point of view of post-graduate learners. In the context of developing research expertise, criticality is conveyed as thinking like a scientist or academic, which is related to being able to theorise (Kiley, 2015; Kiley & Wisker, 2009). Others mentioned critical thinking as a necessary element of the many conceptually challenging academic skills expected to be used and developed for higher-level disciplinary conceptual understanding during postgraduate research candidature (Alpi & Hoggan, 2016; E. M. Johnson, 2014; Kandiko & Kinchin, 2010; Tucker, 2015). For example, Alnajjar and Altamimi (2016) examined their own learning process for an online master's degree course and present a fair argument that critical thinking was a key threshold concept for them as learners. Similarly, B. Hawkins and Edwards (2015, p. 33) in examining management students' learning reflexivity for "thinking like a leadership scholar," found that the ability of a student to think critically appeared to closely fit the threshold concept characteristics in applying this to general knowledge development, and also as a distinct epistemological and ontological shift in itself. General academic writing skills also purportedly require critical thinking skills, ways of thinking and a critical approach, but again, the research falters at the examination of the detailed process. Wisker (2015) details useful findings regarding the process of developing academic writing for literature review and advances aspects such as engaging critically with the literature. She later clarifies this as being where examiners identified articulation of engagement with theory, including examinees being able to "explain" theory, the "integration" of theory with their own ideas, and "developing a story and an argument" (Wisker, 2015, p. 72). These explanations given by examiners imply a high-level application of several critical thinking skills by the students. So, many of these findings include critical thinking elements but few researchers have examined in detail the process of applying critical thinking to conceptual learning within the liminal space to discover how these contribute to learning the academic or research threshold concepts involved. There are two important exceptions.

The first exception was research published by Ricketts (2010, p. 58) who produced useful analysis of learner experience questionnaire data. He detailed his law students' top four responses when asked what they understood by deep learning, as: 1) understanding;

2) applying/cross-relating information; 3) developing one's own opinion; and 4) critiquing/analysing. He states that this level of deeper learning is transformative and uses Brookfield's four criteria of critical thinking to analyse this further (Brookfield, 1987, pp. 7–9): 1) Identifying and challenging assumptions; 2) Challenging the importance of context; 3) Imagining and exploring alternatives; 4) The development of reflective scepticism. Applying these clear critical thinking characteristics as themes to his data he found that his students, when asked to describe new approaches to their learning, mentioned the following descriptions (ranked from highest to lowest): becoming more questioning, becoming more critical, developing new and changed perspective, developing their own opinions and becoming more sceptical. Interestingly, there were some less common descriptors that were less obviously critical thinking skills (Ricketts, 2010, p. 58). His conclusion for postgraduate law research students was that his strategy of improving a deep approach to learning of critical literacy had succeeded, and that being "sceptically aware" is the most important attribute for graduates and educators (Ricketts, 2010, p. 59). For the purposes of my research, this demonstrated that students are capable of describing their learning in terms of critical thinking practice.

The second exception was published more recently by Chen and Rattray (2017) who present a cogent argument that critical thinking is a discrete threshold concept, commonly used by students in moving towards threshold capabilities and therefore employed within the liminal space. This was research conducted in a literacy education context, with an exploration of media literacy students' development of critical thinking capabilities. From their research, they argue that critical thinking, as defined by Magolda's (1992) model, correlates well with the seven characteristics of threshold concepts (discursive and reconstitutive, as well as the basic five) (Chen & Rattray, 2017, p. 278). They explored critical thinking capabilities and threshold characteristics in their data from a media literacy problem-based learning course. Unfortunately, they conclude that the complexity of the topic and the shortness of their follow-up restricted their analysis to short-term learning gains, and this was further limited due to the nature of the teaching practice. However, they were confident that students appeared to be experiencing critical thinking in media literacy learning as a threshold concept, but it was less clear if this was a true threshold concept or more likely a "threshold capability," as it was more complex and having the property of being transferable across subjects and domains (Chen & Rattray, 2017, p. 274).

So, is it possible to conclude that critical thinking is a threshold concept or a threshold capability? In contrast to Chen and Rattray (2017), other researchers have positioned the praxes, skills, and dispositions they discovered to be part of the transformation process separate from the disciplinary threshold concepts (e.g. Tucker, 2012). In addition, research on the interdisciplinary nature of critical thinking highlights the importance of learning these procedural skills (such as critical thinking and reflective practice) within a specific discipline area in order to enable later transference to other disciplines (Entwistle, 2008; Perkins & Salomon, 1992). Furthermore, as demonstrated by the evidence presented above, criticality appears to be key to academic disciplinary development and expertise. Barnett (2009) takes this further and champions a more holistic view, namely that graduates should be supported to become critical practitioners; a state of being he believes is necessary for students and indeed academics to achieve their full potential within the changing, uncertain, "super-complexity" of the world of today (Barnett, 2005, p. 794). Indeed, many TCF researchers touch on a disciplinary expectation for graduates as a critically minded practitioner, necessarily overlaid with specific disciplinary elements, such as creativity for a visual designer (Osmond, Turner, & Land, 2008).

Consequently, several elements of critical thinking will require further investigation in order to understand the conceptual learning moments and to ascertain whether critical thinking is an inherent element of the troublesome and metacognitive nature of the threshold concept as defined by Meyer and Land (2003, 2005). There is some evidence that critical thinking has a conceptual nature, is inherently troublesome, and, as shown above, some researchers consider it to be a threshold concept. Research on the interdisciplinary nature of critical thinking highlights the importance of learning these skills within a specific discipline area in order to enable later transference to other disciplines (Entwistle, 2008; Perkins & Salomon, 1992). Barnett (1997) takes this further and champions a more holistic view, namely that graduates should aim to become critical practitioners; a state of being he believes is necessary for students and indeed academics to achieve their full potential within the world. However, various sociocultural pressures (such as accrediting professional bodies) exert a strong influence on how students learn criticality in higher education. It can be argued that the system creates and frames threshold concepts that in turn define the substance and boundaries of the disciplines. These, in their turn, act to restrict the extent to which students control and extend their mastery of criticality, thus inhibiting the very skill that education claims to value above all others. This strange, convoluted and inter-dependent relationship of critical thinking with the disciplines was examined within the thesis and was contextualised to medical education with recommendations for teaching practice. To contextualise this thesis within the field and discipline, the following section discusses critical thinking within the educational setting.

2.3.5 Critical Thinking in Context

Clinical medicine is a broad field making the exploration of critical thinking in this context more difficult. Medical graduates will have learned across many different disciplinary specialties, using and developing many different procedural, communication, reflective and critical thinking skills. They need to be able to integrate and employ this knowledge with their skills, safely and proficiently, within an often hectic and pressurised clinical environment. Competency based education (Weinberger, Pereira, Iobst, Mechaber, & Bronze, 2010) and competency-based outcomes for professional development, such as CanMEDS (Frank & Danoff, 2007), have been advocated successfully in recent times as a way of bringing these together in the medical practitioner. However, there has been resistance to change and cautions regarding its implementation across the sector (R. E. Hawkins et al., 2015). One concern is that there is an over-emphasis on assessment standards for individual skills resulting in student demotivation and a non-holistic approach that has diminished the development of higher order competencies (Leung, 2002). Furthermore, "transformative learning" was acknowledged as essential for supporting students to become "enlightened change agents" for the 21st century (Frenk et al., 2010, p. 1924). Indeed, enculturation to the so-called 'hidden curriculum' of the local medical culture has been shown to be vital for their survival and acceptance within the institution and for safe practice of medicine (Luke, 2003). This implicit social enculturation of ethical, moral and norm-based values transmitted mostly by modeling has definite dangers, for instance it creates tensions between conforming to the socio-cultural norm versus practising to professionalism standards (Mahood, 2011). However, this sociological process appears to be necessary for the progression from junior to senior doctor, so most junior doctors readily adopt what they perceive to be the correct ways of thinking, acting and practising according to each new medical field and clinical setting that they enter during their specialisation training (Luke, 2003).

Within this sociological, educational milieu, it appears hard to capture what is happening to student learning of critical thinking skills. Historically, medical educators have distinguished the development of students' ability to think critically as a key educational objective because, as Gambrill states: "Decision making is at the heart of clinical practice" (p.3). Both simple and complex decisions are made even during a short and seemingly straightforward patient interview. These critical actions can range from "moment-to-moment decisions" in communication responses, to "judgmental tasks" (Gambrill, 2005, p.4). Clinical errors can occur at any of these points within decision-making moments, judgment calls and problem-solving tasks. As mistakes should be minimised, the actual processes of the skills need to be understood in order for the teaching and learning to be effective. As good decision-making requires good critical thinking skills, medical schools should aim to maximise these, but this is not an easy task especially when there remains a difference of opinion regarding what critical thinking is.

At Harvard University, Krupat and colleagues (2011) have researched how medical teachers think of critical thinking, examining whether they consider it a process, a skill or ability, or a disposition. Their findings show the majority understand critical thinking to be a process or applied skill or ability. Few teachers thought of it as a disposition, which corresponds well to the prevailing approach within medicine. In contrast, Gambrill (2005), in her widely used textbook on clinical practice, describes critical thinking as "a unique kind of purposeful thinking in which we use standards such as clarity and fairness. It involves the careful examination and evaluation of beliefs and actions in order to arrive at well-reasoned decisions" (p. 11). This view suggests that decision-making cannot be separated from ethical, moral and legal frameworks, standards, behaviours and weighing up of options. However, she takes this no further and in her conclusion she limits critical thinking practice to critical clinical decision-making alone, explaining that a good graduate is a competent at carrying out tasks that form a practitioner's role, including critical appraisal of evidence, critical analysis of lab or clinical results, clinical decision-making and problem-solving and critical reflection.

At the University of New South Wales, the key generic graduate attributes approved by the Academic Board in 2003 include: "the capacity for analytical and critical thinking and for creative problem-solving" (McNeil et al., 2012, p. 257). Barrie (2012) concludes that generic graduate attributes are those considered to be the basic skills, knowledge and abilities that enable learning across contexts, yet sit outside of the discipline context itself.

In contrast, Bennett, Dunne and Carré (1999) earlier argued that there are core or discipline-based generic skills. However, most educators agree that these abilities or skills at the heart of student learning and are among the skills that students most aspire to learn for future success in the workplace (Lizzio & Wilson, 2004). At UNSW, course and program developers have adapted the critical thinking criterion to suit the many disciplines across the university. Some course designers have styled this to suit their own learning objectives and/or the requirements of relevant governing or vocational bodies. According to Barrie (2003) this should be more effective for learning than using broader, more general criteria. Interestingly, the critical thinking attribute mentioned above appears to be the one key generic graduate attribute to be adopted by the majority of the university's programs and courses.

Unsurprisingly, the newly reviewed and revised medicine program at UNSW was the first to align all its objectives and assessments to its own specific graduate attributes for the new medical program launched in 2004. The program developers followed the example given by medical post-graduate training and regulatory organisations who had recently moved towards competency-based training and models. These aligned the required learning objectives, student learning and assessment of the specific skills desired for the final product, the future generalist or specialist (Sherwin, 2011; Weinberger et al., 2010). At UNSW, the current medical program curriculum is designed around eight graduate capabilities that underpin the whole curriculum and act as an outcome framework for assessment (see Figure 2.5) (McNeil et al., 2012).

1. *Understanding basic and clinical sciences in the practice of medicine*
2. *Understanding the social and cultural aspects of health and disease*
3. *Patient assessment and management*
4. *Effective communication with patients, team members, colleagues and the community*
5. *Working as a member of a team*
6. *Self-directed learning and critical evaluation skills*
7. *Understanding ethics and legal responsibilities in medicine and acting in a socially responsible manner*
8. *Development as a reflective practitioner.*

Figure 2.5 UNSW Medical Program Graduate Capabilities
(McNeil et al. 2012. Taylor & Francis Ltd: www.tandfonline.com)

This graduate framework is fully embedded and fully mapped across the curriculum and has been shown to be used reasonably effectively by teaching staff and students

(Watson, 2013). Further, it was acclaimed nationally by the prestigious Australian Office of Learning and Teaching with the Award for Programs that Enhance Learning (Medicine, 2014). However, in my estimation, the program, specifically its assessment, has failed to deliver balanced learning across the capabilities. This is due to some emphasis on critical thinking skills, as *clinical reasoning*, which is developed across the three phases (in five of the six years) and *critical evaluation* of evidence (introduced in the first phase (first and second year), applied to clinical practice in Phase 2 - third and fourth year) (McNeil et al., 2012). However, the extended understanding of critical practice or critical being is not included as an expectation, and other critical thinking skills are not represented. Even the graduate capability ‘Development as a reflective practitioner’ lacks mention of the word “critical” in its twenty-one criteria standards covering the six years of the program. This might not be an issue for graduate learning of our medical students overall, but this lack of specificity could have a detrimental effect on how students learn and their personal development. Interestingly, there is considerable, renewed interest and pressure from the overseers of the undergraduate internship programs, including the Australian Medical Council that programs specify and delineate the ways in which competencies are taught and how they are assessed (e.g. Carmichael & Hourn, 2011). This has added further impetus to the purpose of this thesis.

The Focus of this Thesis

In summary, although there are many theories about how critical thinking aids our conceptual understanding, few examine the critical thinking processes involved. Barnett (2009, p.433) postulates that “the acts of and processes necessarily required in coming into a secure relationship with knowledge themselves have educational effects.” So, the actual journey towards knowing is at least as useful, if not more so than the arrival at the understanding of the knowledge. This is tremendously important as it establishes that is it useful to gain more useful, higher-level critical skills, for the learner to become a critical being or critical practitioner (Barnett, 1997; Brookfield, 2005). However, most importantly, the learner also needs to be able to transfer these skills across disciplines and into different practical contexts (Barrie, 2003; Entwistle, 2008; Perkins et al., 1993; Perkins & Salomon, 1992).

So, in aiming to understand critical thinking for conceptual learning in threshold concept crossing, there are several challenges. Firstly, how does a learner develop an understanding of a troublesome concept? Secondly, what helps the learner to finally understand (are there key learning factors or a tipping point) for this to be a transformative shift in understanding? Consequently, does each *conceptual* leap forward by the learner produce a gain in their critical thinking ability that can be transferred to further practical applications by the learner? Lastly, is critical thinking a threshold concept or is it something else? More specifically, there are contextual research questions that arise from this evaluation of the literature. Foremost, are the gaps in understanding of conceptual learning, with pressure from regulatory bodies and future employers to examine more carefully whether we are developing students' critical thinking abilities adequately. Furthermore, research suggests that the teaching of evidence-based practice and medical biostatistics is not straight-forward and lacks a strong research base around transformative learning and critical thinking for this conceptual understanding. Therefore, my thesis aimed to explore critical thinking within conceptual learning of medical students when crossing the liminal threshold of concepts in evidence-based practice and medical biostatistics. The next section examines the theoretical background for the methodology used in the thesis.

2.3 THE THEORY: VYGOTSKY

The previous sections evaluated the literature around conceptual learning and critical thinking to provide a firm research background and justification of this thesis. This section goes on to examine critically and explain Vygotsky's theories and how these were employed within the analytical theoretical framework of this thesis. It will demonstrate how Vygotsky's ideas mesh with the Threshold Concept Framework, in preparation for explanation of the methodology presented in the next chapter.

2.3.1 Origins

Lev Semyonovich Vygotsky was active during the first third of the 20th century. He was a Russian Jew researching in Russia before and after the revolution of 1917, which affected his impact then and his current legacy. However, his stature was commensurate with Piaget's during his lifetime. Vygotsky died young, but fortunately, his followers extended his work with later research within Marxist and general educational approaches. This work led to the development of significant educational models, such as the often-employed practice of *scaffolding* learning, an emphasis on instruction in conceptual learning, and several approaches based on his well-known zone of proximal development (ZPD).

Although his educational research might be considered outdated today, I will argue that his theories can provide interesting insights into critical aspects of conceptual learning.

Born into a middle-class eastern European Belarusian Jewish family in 1896 (Kotik-Friedgut & Friedgut, 2008), Vygotsky lived and worked during a time of great intellectual, scientific, and social change during the last decade of Russia's "Silver Age" of culture and philosophy (Veresov, 2009, p. 32) and through the cultural transformation of the Bolshevik revolution (van der Veer & Valsiner, 1991). After university studies in law, history, philosophy and education (Gredler & Shields, 2008), Vygotsky pursued research in literature, drama and education (Michell, 2015; van der Veer & Valsiner, 1991) until his appointment to the Institute of Experimental Psychology in Moscow in 1924 where he soon became the leading intellect (Kozulin, 2012). At the Institute, Vygotsky lead a team of scholars in a Marxist-inspired (Rowlands, 2000; Veresov, 2009) program of cultural psychology research (Cole, 1996), investigating all aspects of the nature and development of human consciousness (Elkonin, 1998). Using principles of Marxian-Hegelian dialectic, Vygotsky's "philosophy-psychology" (Robbins, 2001, 2007, p. 87), interrogated and extended current theories of psychology schools in Russia and abroad to develop new ideas on child development, thought, and language mediation of conceptual learning, and his well-known zone of proximal development (ZPD) (Chaiklin, 2003; Howe, 1996; Kozulin, 2012).

After Vygotsky's death from tuberculosis in 1934, his colleagues continued to develop his theories, but these were not widely known outside Russia until serial publication of his *Collected Works* in English translation, 1987-1999 (Kozulin, 2012). Since then, researchers within Russia and across the world have further developed Vygotsky's wide-ranging theories, advancing our understanding and practical application of the development of mind in society and education (e.g. Chaiklin, 2003; Howe, 1996; Karpov & Bransford, 1995; Kozulin & Presseisen, 1995; Zaretskii, 2009). Bakhtin, Luria, Leont'ev, Engeström, and more recently Wells have developed Vygotskian ideas around semiotics, activity theory, making-meaning and language (Kilgore, 1999; Langford, 2005, pp. 14–23). In addition, Karpov, Branford and others have established their research around conceptual learning, building upon Vygotsky's educational development theories (Karpov & Bransford, 1995). Vygotsky's model of instructional conceptual learning, the ZPD, is used extensively across educational practice (Verenikina, 2003) and research (e.g. Harland, 2003). Most recently, cognitive psychologists have touched upon Vygotsky's theory regarding language and thinking in their investigation and analysis of inner speech (Fernyhough, 2016).

Criticism of Vygotsky's theories is not uncommon, especially regarding the philosophical approach and rigor of his research work. Supporters of Vygotsky, such as Lui and Matthews (2005) and Robbins (2001, 2007), consider this to be due to confusion and misunderstanding of the historical approach exacerbated by difficulties of aligning current and past paradigms. The main elements of his theories are discussed below.

2.3.2 The Vygotskian Approach

Vygotsky's educational development research is well respected across the world and across educational establishments; his theories are knowingly, and perhaps unknowingly, applied in everyday teaching within a variety of types and levels of pedagogy. Despite not being an active advocate of constructivism and moving from a socially progressive educational standpoint to semi-traditionalist just before his death (Langford, 2005), Vygotsky's conceptual learning theories appear to fit well with the current constructivist student-centred perspective dominating modern educational institutions. Indeed, Vygotsky's socio-cultural approach has been mentioned as essential to the effectiveness of his theories within developed nations and their mostly non-Marxist, education systems (Rowlands, 2000; Veresov, 2009). Significantly, he believed in the "primacy of culture in shaping development" (Howe, 1996, p. 37), the sociocultural, human interaction within institutions and the environment triggering and supporting a child's psychological development.

In agreement with his contemporary Piaget, Vygotsky's research was child-centred, but they were at variance regarding the origin of the influences on child development. Piaget's objectivist approach led him to disregard culture and external instruction as an influence on development, instead focussing on the intrinsic development process (Bruner, 1997). In contrast, Vygotsky emphasised the role of the child's immediate social environment, considering the central relationship with the 'instructor' as key to development of conceptual understanding, and for supporting the child's development towards a higher cognitive ability (Chaiklin, 2003; Kozulin, 2012; Zaretskii, 2009). "The zone of proximal development," Chaiklin (2003) observed, "is not simply a way to refer to development through assistance by a more competent other. This assistance is meaningful only in relation to maturing functions needed for transition to the next age period" (p. 58). This is defined as the *mediated learning experience* and is fundamental to the Vygotskian view of development and the conceptual learning of the child. This semiotic mediation is carried out through the use of tools (environmental and psychological), and human mediators "as carriers of signs, symbols and meanings" (Kozulin & Presseisen, 1995, p. 69). A tool mediates material activity, whereas a sign's function is to be the means of "psychological activity" discourse – individual or social (Vygotsky, 1978, p.52).

Taking this further, Vygotsky's socio-cultural approach can be said to work effectively in parallel with current educational development models. For example, followers such as Wells advocate the usefulness of Vygotsky's semiotic mediation theories as a powerful tool in explaining and supporting children's "understanding of their world … in terms of a co-construction of knowledge through jointly conducted activities that are mediated by artifacts of various kinds, of which dialogue is the most powerful" (Wells, 2007, p. 245). In addition, if Vygotsky's theory is viewed as a Marxist objectivist perspective (Rowlands, 2000), further application of his theories can be attempted. For instance, scientific concepts and concept networks, as well as the mediated learning experience outlined by the zone of proximal development, can be applied to learning and teaching in all levels of education. This approach appears valid and workable. A wide variety of disciplinary fields have adapted these educational theories and associated strategies (see Hammond, 2001; Howe, 1996; Michell, 2012; Pea, 2004; Wass, Harland, & Mercer, 2011). Moreover, in terms of the methodological research approach Vygotsky's socio-cultural perspective fits well with the analytical methodologies used in this research, as examined in the next chapter.

2.3.3 Vygotskian Theory

Recent approaches in education have looked beyond the teaching and learning of curricular knowledge and led to a reexamination of conceptual learning that focuses on the desired outcome of the ability to learn (Halpern, 2014; Land, Cousin, Meyer, & Davies, 2006; Sands, 2014). As a result, higher education research has placed greater emphasis on the need to examine the development of cognitive and other 'higher' faculties in conceptual learning. An essential, reciprocal and symbiotic relationship is widely acknowledged between conceptual learning and cognitive development (Entwistle, 2008; Land et al., 2006).

Forms of Thinking

Vygotsky (2012, p. 167) identifies two fundamental forms of thinking – spontaneous, "everyday" concepts, and non-spontaneous, "scientific" (academic or theoretical) concepts. These, whilst intersecting, are fundamentally different in origin, being induced "under entirely different inner and outer conditions" initiated by different *objects* (motivations and learning stimuli). The different nature of these two forms of thinking arises from their different developmental origins. The distinguishing attribute of non-spontaneous, scientific concepts (hereafter, 'academic') is that they are acquired through formal education and are part of an interconnected system of abstract ideas whose meanings are mediated and determined by their relationship with other ideas (Vygotsky, 2012, p. 181). In contrast, spontaneous concepts arise from an everyday, commonsense experience of the world. The spontaneous concepts were Piaget's idea and he considered this to derive purely from a child's own mental exertions. However, in contrast to Piaget, Vygotsky emphasised that these concepts develop through socialisation and "everyday living" (Vygotsky, 2012, p. 164), initially as unstructured, unconscious or subconscious concepts derived from informal learning from new stimuli. Further, he argued that such concepts comprise the implicit knowledge that facilitates our progress through everyday life and day-to-day, social communication (Vygotsky, 2012). These spontaneous concepts clearly equate with the "tacit" nature of the knowledge described originally by Meyer and Land (2003, p. 7), where previously learned, unconscious elementary concepts are necessary for the active understanding of new threshold concepts.

In contrast to spontaneous concepts, Vygotsky identified the higher-level, non-spontaneous academic concepts as being different. These "start in the child's mind" as verbal definitions and subsequently are internalised through conscious use (Vygotsky, 2012, p. 204). He emphasised that academic concepts reflect, and are part of, a wider interconnected system of concepts. In fact, he deemed a system necessary for productive thinking:

> Concepts do not lie in the child's mind like peas in a bag, without any bonds between them. If that were the case, no intellectual operation requiring coordination of thoughts would be possible, nor would any general perception of the world. Not even separate concepts as such could exist; their very nature presupposes a system. (Vygotsky, 2012, p. 209)

Indeed, Vygotsky went on to develop theories around conceptual networks, considering a conceptual network necessary for ordinary, everyday thinking and interaction, as well as for higher-level thinking.

The Nature of Higher Learning

To appreciate the nature of this higher thinking and learning, it was therefore necessary for Vygotsky to understand how these different epistemic processes relate and how their transformation comes about. Instead of seeing development in Piagetian terms of separate development between the child's spontaneous and conceptual thinking, Vygotsky saw learning as a dialectic, two way interaction between academic and everyday concepts, "making everyday experience fit into the scientific conceptual system and applying the systematic construct to everyday experience" (Howe, 1996, p. 40). He postulated that spontaneous concepts "proceed upward" from the child's elementary subconscious or even unconscious understanding to become more conscious and deliberate in their use, rising up to the cognitively higher level of the academic concepts (Vygotsky, 2012, p. 205). Further, under certain conditions, academic concepts can exert a meditating influence on spontaneous concepts, transforming them and restructuring the child's thinking into a more organised, system of concepts. He described this as:

> In working its slow way upward, an everyday concept clears a path for the scientific concept and its downward development. It creates a series of structures necessary for the evolution of a concept's more primitive, elementary aspects, which give it body and vitality. Scientific concepts, in turn, supply structures for the upward development of the child's spontaneous concepts towards consciousness and deliberate use. Scientific concepts grow downward through spontaneous concepts; spontaneous concepts grow upward through scientific concepts. (Vygotsky, 2012, p. 205)

Thus, he considered that spontaneous and academic concepts connect in the learner's mind to become grounded more concrete, fully understood concepts. This is very similar to the integration and irreversibility mentioned by Meyer and Land (2003, 2005). Furthermore, Vygotsky relates this dialectic interaction and fusion of concepts to transformative outcomes, epistemic and ontological shifts, similarly described by the TCF (Meyer & Land, 2003, 2005). He emphasised that it is a learner's conscious, voluntary control, internalisation, and systematisation of concepts that enables their generalisation and transfer. This ontological shift is of vital importance to learning. He explains that "mastering a higher level in the realm of scientific concepts also raises the level of spontaneous concepts. Once the child has achieved consciousness and control in one kind of concept, all the previously formed concepts are reconstructed accordingly." (Vygotsky, 2012, p. 203). This dialectic process (depicted in Figure 2.6 below) describes how previously learned everyday concepts assist in the learning of more complex, academic concepts. It shows how initial spontaneous concepts or tacit knowledge are transformed in this process with a further benefit that "reflective consciousness comes to the child through the portals of scientific concepts" (Vygotsky, 2012, p. 181). This model of conceptual learning is still used today by educationists, psychologists, practitioners and researchers. As a basic model, it remains useful and will be discussed further in Chapter Four.

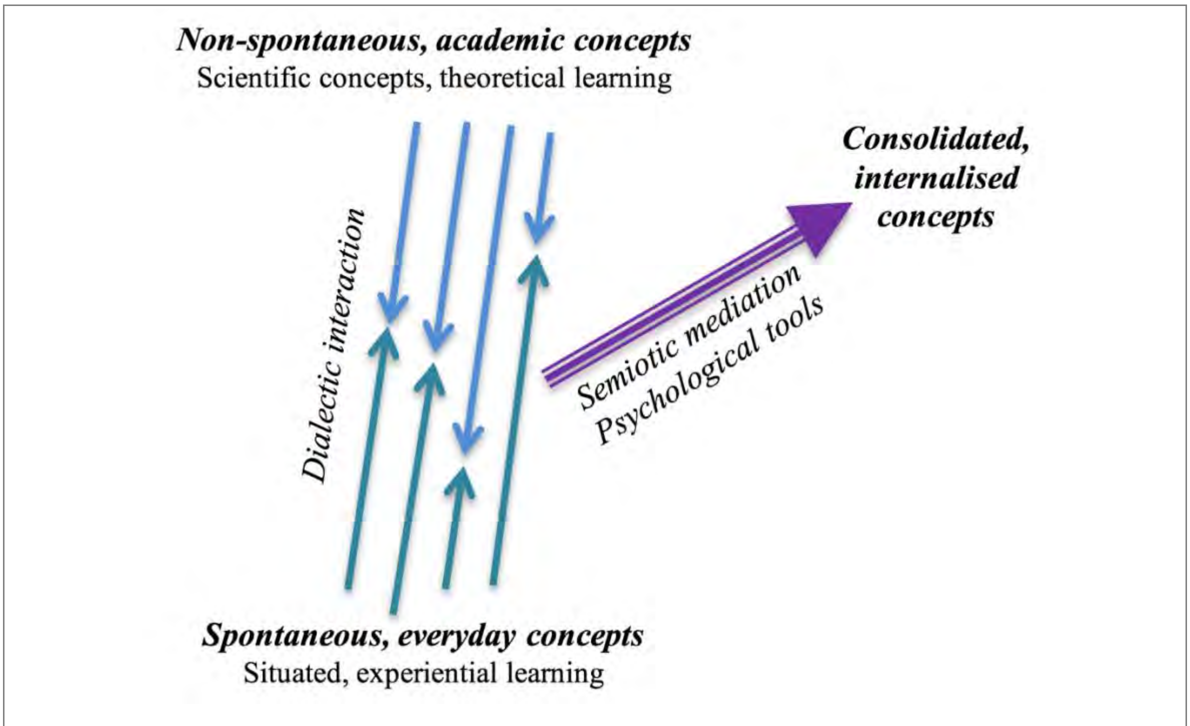

Figure 2.6 Conceptual learning according to Vygotsky

Vygotsky's Conceptual Network

Vygotsky (2012) proceeded to explain that the development of academic concepts is part of an organised, system of concepts in the learner's mind, which is synonymous with the development of the higher mental operations of conscious awareness and volition. He maintained that mastery of a knowledge domain derives from developing a conceptual system or structure where the "principle of the relations of generality" applied in the learning of academic concepts (Vygotsky, 2012, p. 216). This structure develops from the integration of a new scientific concept into "an internal hierarchical system of interrelationships" of concepts that allow application of these to other "domains of concept and thought" (Vygotsky, 1987b, p. 191). This model accords with the TCF's idea of threshold concepts as a binding together of concepts that enable the ways of thinking and practising in a discipline (Land et al., 2005, p. 54). As described previously, these can appear to be linked together as conceptual networks in an integrated system of concepts characterising the epistemic status of the disciplinary expert. Importantly, Vygotsky (2012, p. 216) called thinking conceptually, realistic or "real thinking." In his later work, he developed the idea of a deliberate, systematic organisation of academic concepts, saying that the "conscious use of concepts simultaneously implies that concepts can be controlled voluntarily" and argued that this is achieved through systematisation (Vygotsky, 2012, p. 184).

To explain this systematisation, he used an analogy of the longitude and latitude of the globe for the mapping of theoretical concepts in learning. Vygotsky suggested that these could be different but similar at the same time (e.g. learning of the words flower and rose are his example). Longitude is the "thought process" involved and latitude is the "objective reference" (Vygotsky, 2012, p. 211). He gave these relational concepts the names "coordinate," "superordinate," "subordinate" and explained that when the student takes on the challenge of learning concepts within this globe-like net of coordinates, she creates an "intellectual operation" generating pathways of thought linking the concepts (Vygotsky, 2012, p. 211). Thus, similar abstract ideas that relate to the same topic area (e.g. organisms: plants, animals, bacteria etc.) might be positioned on the same longitude in the conceptual network but have different latitudinal positions. In addition, more complex or broader concepts could be "a line" rather than a single location in this network of concepts (Vygotsky, 2012, p. 211). Thus, Vygotsky visualised a three-dimensional globe-shaped network that is created as the child develops an understanding and concretes theoretical concepts in her consciousness (see Figure 2.7 below). It is easy to imagine the conceptual thought process that Vygotsky talked of, with the movement between these concepts being pathways of thought, moving across the conceptual globe. Once concepts are linked directly through this process, they are available for use in further thought and communication to others through language and for "intellectual operations" of the critical thinking skills of "comparisons, judgments, conclusion" (Vygotsky, 2012, p. 212).

On reflection, this globed network of conceptual learning would be useful for mapping threshold concepts and identifying links between concepts. It could provide a useful visual model on which a learner could consolidate academic concepts within a disciplinary field. Hence, this thesis used Vygotsky's ideas regarding the essential presence of conceptual networks and forms of thinking to examine the conceptual processes as they interrelate as part of the threshold concept learning process. The following section examines Vygotsky's major contribution to our understanding of the intersection between thought and language.

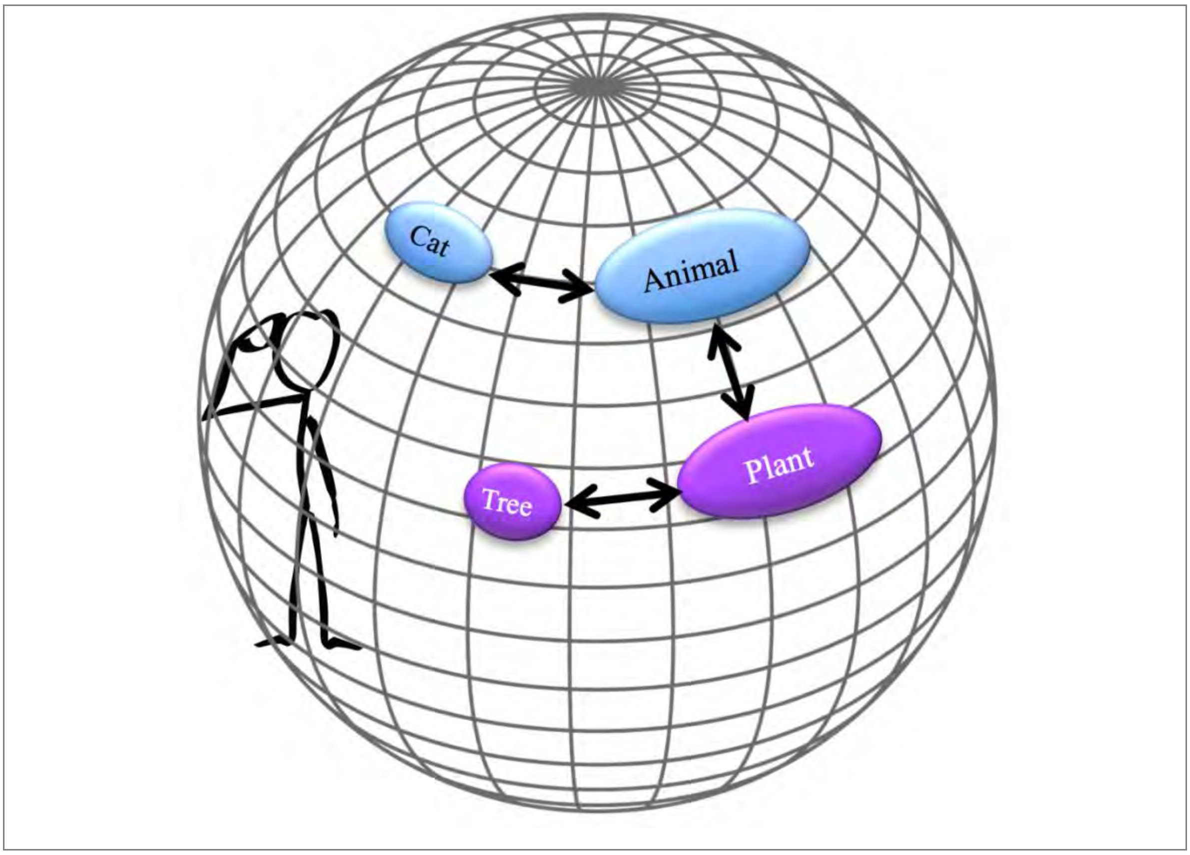

Figure 2.7 Vygotsky's globe-shaped network of conceptual thinking

Language and Thinking

Within Vygotsky's scheme of development of higher mental functions, language mediates elementary perception, transforming and developing it into a higher intellectual form as categorical or generalised perception. By integrating with language-based conceptual thinking, perception thus becomes intellectualised as "intelligent perception" (Vygotsky, 1998a, p. 90). For Vygotsky, language was the mediator to the conceptual development, intellectualisation, "making meaning" and beyond (Vygotsky, 2012, p. 181). In his work published in English as *Thought and Language* (Vygotsky, 2012) and *Thinking and Speech* (Vygotsky, 1987b), Vygotsky outlined a comprehensive theory of the role of language in thinking. At the core of his theory was that human language is the key tool of signification and the making of meaning. Essentially, he believed that in the course of their development, a child's social and internalised social speech becomes a transformative mediating tool for concept development and thinking:

> Real concepts are impossible without words and thinking in concepts does not exist beyond verbal thinking. That is why the central moment in concept formation, and its generative cause, is a specific use of words as functional 'tools'. (Vygotsky, 2012, p. 115)

This theory of language, words being tools for conceptualisation, was elemental in my approach to the data analysis.

Additionally, as part of his account of the development of thinking, Vygotsky outlined how a child's social speech with others is internalised as "egocentric" or private speech, which eventually develops into "inner speech," or verbal thinking (Vygotsky, 2012, p. 92). Vygotsky argued that, through language socialisation, mediation and internalisation, language is a crucial semiotic resource for behavioural self-regulation, and the development of human intellect and personality. In this process, use of speech as a psychological tool acts to regulate its user and also stimulate development of the higher mental functions of perception, memory, attention, abstract thinking and volition:

> …speech, being initially the means of communication, the means of association, the means of organization of group behavior, later becomes the basic means of thinking and of all higher mental functions, the basic means of personality formation. (Vygotsky, 1998b, p. 169)

Vygotsky believed that it was in the context of collaborative dialogue that the learner's psychological development and thinking is actively stimulated, and their concepts and conceptual networks developed. Here, Vygotsky made important distinctions between the nature and functions of social or external speech – language 'for others'; egocentric speech – language 'for the self'; and inner speech – language 'of the self', where words meld into transitory, partly conscious or non-conscious thoughts or images:

> Inner speech is to a large extent thinking in pure meanings. It is a dynamic, shifting, unstable thing, fluttering between word and thought, the two more or less stable, more or less firmly delineated components of verbal thought. Its true nature and place can be understood only after examining the next plane of verbal thought, the one still more inward than speech itself. That plane is thought itself. (Vygotsky, 2012, p. 264)

According to Vygotsky, inner speech connects our thoughts with expression of our thoughts. Since, "a thought may be compared to a cloud shedding a shower of words" (Vygotsky, 2012, p. 266), inner speech can be seen as internalised social speech compressed as verbal thought which may, in turn, be decompressed, and externalised for external expression in words as speech. In this way, inner speech links meaning and sense through its culturally-loaded "sign system" (Wells, 2007, pp. 246). As previously mentioned, according to Vygotsky, one manifestation of this meaning is constructed in the mind as real or realistic thinking, which is logical, rational and constructed (Vygotsky, 2012, p. 216). This is crucial to conceptual thinking and therefore conceptual learning. Hence, for this research the data was approached with the intent of examining dialogue with others, and to find out if students were aware of using inner speech in their learning.

The Zone of Proximal Development

The ZPD is probably one of Vygotsky's most well-known and possibly most adapted ideas. In describing the ZPD, Vygotsky, identifies two thresholds. These thresholds establish two cognitive developmental limits for the developing child, an upper level or ceiling of prospective development at its height, and a lower level or floor of the child's actual development at its base (Vygotsky, 2012). The gap or height between these thresholds creates the developmental space for cultural imitation, mastery and becoming which defines the ZPD. The two thresholds of the ZPD, the ceiling and the base, define the currently available sphere of productive instruction, determining its sensitivity and efficacy for a child at a certain age period. The upper and lower thresholds of the ZPD are pedagogically significant since the developmental zone they create identifies an ideal time for a child's age and stage:

> It is important to determine the lower threshold of instruction. … It is equally important to determine the upper threshold of instruction. Productive instruction can only occur within the limits of these two thresholds. Only between these thresholds do we find the optimal period for instruction in a given subject. (Vygotsky, 1987b, p. 211)

So, for a child these upper and lower thresholds are changeable depending on the individual and their current development. Vygotsky was clear that the ZPD is not static; the two thresholds reflect dynamic relations of development whereby, during the course of instruction, the intellectual potential of academic instruction (the ZPD) is actualised in the learner's intellectual development (the ZAD). In turn, this raises the learner's intellectual potential to a new level that requires even higher-level instruction and intellectual challenge within a new ZPD, with new upper and lower thresholds (as represented in Figure 2.8 below).

The child as the learner is not isolated in experiencing this development. Instruction in the form of a teacher or learned peer is essential to Vygotsky's view of this learning zone; the instructor enables the intellectual learning process from the lower to the higher threshold. So, the ZPD is a dynamic learning zone, but it is also a *relational* zone, meaning that higher forms of human thinking are formed and developed in dialectic interaction with cultural agents and artefacts (Kozulin & Presseisen, 1995). As such, the ZPD provides a holistic perspective of a learner's intellectual learning and development through social collaboration (Kozulin & Presseisen, 1995). In examining these dynamic and relational processes and relating this to the TCF liminal space, it appears that the transformational result of grasping a threshold concept is equivalent to the dynamic movement of the learner's intramental development from the ZPD to the ZAD, with the creation of a new ZPD from the learner's zone of far development (ZFD).

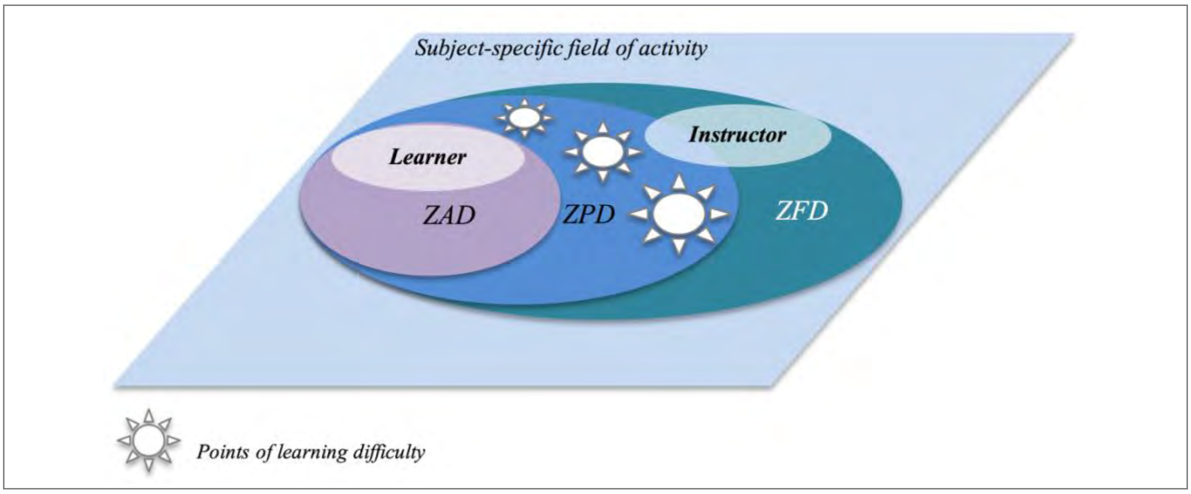

Figure 2.8 Representation of the zones of development

(Based on Zaretskii 2009, p. 82. Taylor & Francis Ltd: www.tandfonline.com)

ZAD: zone of actual development; ZPD: zone of proximal development; ZFD: zone of far development

Learning in the ZPD requires cognitive extension and Zaretskii (2009) extends Vygotsky's theories of specific points of learning where extra assistance may be necessary (see Figure 2.8). Zaretskii argues that these problem points are where the help of the instructor or more learned peer can be of most assistance, and where specific teaching assistance may be needed. He explains that there are different planes of intervention: 1) where the learner is working with the instructor "to assimilate the subject matter that has caused the difficulty"; 2) where the learner is working to resolve the learning difficulty independently (Zaretskii, 2009, p. 81). He advocates that the instructor must be able to recognise that both of these planes of learning are essential. The first plane leads to understanding of the conceptual knowledge, but the second plane ensures the students own development (Zaretskii, 2009, pp. 81–84). Indeed, Zaretskii (2009) proposes that instruction that just feeds the learner with the answers or models of answers, including Vygotsky's suggestions of imitation, guidance and collaboration, is inadequate and may be harmful for a child. He recommends that the child acquire the necessary learning abilities to move actively through their own effort from the lower to the higher threshold (Zaretskii, 2009, p. 91). This then would result in a learner with a better outcome as she would be better able to navigate the next ZPD or point of learning difficulty. These ideas will be discussed and developed further in later chapters.

2.3.4 Vygotsky for this Thesis

Vygotsky focused his research on language with semiotics as the mediator of thinking and meaning-making. These ideas of inner speech could be very useful in analysing what is now called deep learning, specifically in terms of conceptual learning. Again, in contrast to Piaget, Vygotsky believed strongly that language was essential for realistic thinking, conceptual thinking and indeed for imaginative thinking. Furthermore, he considered that these forms of thinking were all directly linked to "meaning making" (Gajdamaschko, 2006, p. 37). If inner speech is in fact a key element of our conscious realistic thinking as well as inherent to conceptual thought and imaginative thinking (Vygotsky, 2012), then it is worth examining how argumentative reflection and other inner discourse enables us to grasp concepts. There must be an essential internal cognitive process that brings together our previous experience of concepts. My thesis will examine how fixed knowledge and memory are brought together using a critical approach and self-reflection to produce the conceptual understanding required for crossing the threshold (Meyer & Land, 2003) or, equivalently, moving on from the ZPD to the ZAD (Vygotsky, 2012).

Importantly, this cognitive approach works together with language. The instructor works collaboratively with the student using communication, discussion and reasoning to assist her to move on from that initial point of difficulty (Zaretskii, 2009). Wass, Harland and Mercer (2011) described how "verbal scaffolding" and "conversation" helped their undergraduate zoology students think critically and approach their learning more maturely to "extend their ZPD for critical thinking" (p. 317). Similarly, McCulloch and Field (2014, p. 4) have used Vygotskian and academic discourse approaches to create "linguistic ‘bridges’” to good effect to support student learning in the university classroom. This generates a further question that will be examined in the thesis, regarding the nature of inner speech and whether it is monologic or dialogic. Examination of these inner conversations should inform the examination of this close relationship between thinking and language in learning.

Taking this idea of learning through or as language further, one finds that semiotic theory has been applied in several ways for educational research, with a surge of interest in the past few years. Wells (2007) provides a balanced and thorough summary of semiotic theory. In addition, a semiotic approach to examining the liminal space of threshold concepts has been outlined by Land, Rattray and Vivian (2014). This provides a useful interpretation of semiotics in the area of conceptual learning and knowledge development. The detailed graphical representations of a dynamic, semiotic liminal space could provide a new way in which to investigate this difficult area. Although the semiotic approach is new in terms of its application to the liminal space, previous qualitative pedagogical research has successfully examined this semiotic and dialogic approach. For example, L. Brooks, Swain, Lapkin and Knouzi (2010) have cleverly shown that conceptual learning underpins the development of a grammatical concept of a French ‘voice’ for university level students. Earlier, Chi and colleagues (1989) used talk-aloud protocols to demonstrate how undergraduates use self-explanation for problem-based learning, and other modern conceptual learning research is re-using this method. Overall, language and thought seem to be conducive to explanation using semiotic theory, so this was considered for use in the theoretical approach to data analysis in this thesis.

2.3.5 The Theoretical Framework

Vygotsky’s teachings can add greatly to our current educational practice. His ideas of dynamic development and learning through instruction for academic concepts and his understanding of cognitive educational development through the zone of proximal development provide fertile ground for learning more about the conceptual transformation and critical thinking in higher education. For this research, I applied his theories to the Threshold Concepts Framework of Meyer and Land (2005) in order to shed light on the murkier, less easily understood depths of this useful modern approach to teaching concepts within disciplines.

As presented above, the threshold concept framework (TCF) is a recently developed approach to reconsidering disciplinary learning. It has gained considerable traction across the education sector as it related well to the needs of educators in their teaching of curricular content. Previous research using the TCF has mostly focused on higher education disciplines but there are keen champions across high school education. This research is less formally peer-reviewed, but high school education has an increasingly active policy to share their pedagogical research and approaches, which has resulted in the dissemination of well-researched reports, conference presentations, blogs and websites. These provide information on recent research and demonstrate practical curricular application of the TCF approach in several key high school subjects, including: photography (Nicholls, 2015; Nicholls & Francis, 2017), geography (C. Brooks, 2017; Slinger, 2011) and history (Adler-Kassner, Majewski, & Koshnick, 2012; Díaz & Shopkow, 2017; Thorne, 2015). This applied research clearly demonstrates improved student outcomes following identification of threshold concepts and pragmatic application of the TCF in the curricular approach at the high school level across varied curricular subjects.

Likewise, in the higher and post-university education sectors, a second wave of research of professional practice disciplines has begun, as documented in the edited volume by Land, Meyer and Flanagan (2016), which includes research from: engineering, medicine, nursing, computer science, legal practice, teaching, and architecture. For instance, in medicine, Wearn, O'Callaghan and Marrow (2016, p. 223) describe the painful transformation process of "'becoming' a practitioner" experienced by junior doctors undertaking palliative care training and suggest that this is a vital process that needs further investigation. In addition, there is a considerable amount of research around threshold skills. For example, across education sectors, writing and composition has come under the TCF spotlight with an edited collection of practically focused research (Alder-Kassner & Wardle, 2016). Introducing this book, Blake Yancey (2015, p. xviii), explains that the authors employed the TCF in writing pedagogy to not only identify 37 threshold concepts as a conceptual map, but, moreover, to show how to employ these concepts proactively in pedagogical contexts. She emphasises that this approach was "a collective philosophical exercise involving exploration as much as consolidation of what we know" (Blake Yancey, 2015, p. xviii).

Other TCF-mediated research has identified and practically integrated threshold concepts within and across disciplinary curricula, including skill-based thresholds. Threshold concepts have been identified amongst information literacy skills by university librarian authors across the world, e.g. (Blackmore, 2010; Townsend et al., 2011). Similarly, there is a growing body of work on the threshold concepts and skills encountered by postgraduate learners. The research into threshold concepts in doctoral candidature and post-doctoral research skills has identified several key troublesome thresholds, mostly skills, which can inhibit the PhD student's progress, and further discussed possible application of this in guidance of doctoral candidates (Kiley, 2009, 2015; Kiley & Wisker, 2009; Mullins & Kiley, 2002; Wisker, 2015). This has led to further research within other postgraduate learning areas, where different types of learning have been employed to facilitate transformative learning. A good example is where enquiry-based learning (EBL) has been shown to be effective in assisting transformative conceptual learning resulting in both epistemological and ontological changes in postgraduate education certificate training of healthcare workers (Pearce, 2014). Together, these examples demonstrate a clear link between the TCF research within all levels of education and clear, applied outcomes within curricula and training of educators. The implication for this thesis is that the TCF approach works practically within many disciplines to identify, map and troubleshoot the complex learning concepts that students find most difficult.

There are many TCF approaches, which makes a choice difficult. Fortunately, the ITCK (introduced above) offers a more focused, but at the same time more sophisticated exploratory approach (J. A. Timmermans & Meyer, 2017). In deriving this new framework Meyer and Timmermans (2017) re-examined previous seminal research to re-explore the fundamental basis of conceptual learning is understanding. They advocate good pedagogy as being the teaching to students of ways to understand the different types of knowledge that underpin the threshold concepts within disciplines. Further, they state that research into this process should explore how the cognitive, affective and ontological knowledge within the liminal space translates into the "*in situ* 'threshold concept representations'" of the student learner (Meyer & Timmermans, 2016, p. 33, emphaisis in original). Meyer and Timmermans (2016) suggest a return to trusted research approaches that were effective in earlier research, such as detailed interviews and transcription of what the students are experiencing in terms of their conceptualisation (Entwistle & Marton, 1994). This approach has been validated in case study, which shows how to use analytical assessment activity tasks to confirm a threshold concept and support student learning of undergraduate engineering (Meyer et al., 2016; Meyer, Knight, Callaghan, & Baldock, 2015). This more refined TCF research approach correlates well with the Vygotskian approach taken in this thesis, aiming to examine the whole dynamic system*,* rather than the individual essential elements. Therefore, the ITCK theory was included in the thesis research framework when it was published, during the first year of analysis research. This refocused the analytical method on the student learning process (and detail within the data from the student case interviews) and provided increased awareness of the different types of knowledge involved in the process under examination.

VYGOTSKY AND THRESHOLD CONCEPTS

Examining the works of Vygotsky led to a deeper understanding of conceptual learning and enabled a theoretical leap forward to focus on the conceptual crossroads point, the crucial moment of transformation in student learning. This moment appears vital to understanding the importance of critical thinking and the potential to assist students in their conceptual learning. However, researching this process is not an easy task. Almost everyone has experienced the transformational power of at least one threshold concept, but this is usually a covert and complex transformation process, buried within the individual's mind, directed by internal and external conversations, nurtured by varying teaching practices and learning modes. Fortunately, the TCF provides a clear structure for identifying threshold concepts and viewing the conceptual learning of disciplinary subjects.

Together, Vygotsky and the TCF are powerful, parallel conceptual theories that can unlock the mysteries of both knowledge and procedural learning. Vygotsky's theories on conceptual learning development appear useful; his emphasis on language and thought will be valuable. Moreover, his key theories synergise well with the threshold concept framework and liminal space model. The learner thinking critically and reflectively makes this process a powerful transformational moment. In unraveling the process, it was essential not to lose sight of what was happening in the mind of the student, at the moment of transformation, within the liminal space. Consequentially, the main aim of my thesis was to examine this process in detail, as holistically as possible, whilst also examining its constituent parts.

In conclusion, conceptual learning and critical thinking are difficult to examine and defy full explanation. By combining powerful models of conceptual learning from

Vygotsky and Meyer and Land's Threshold Concept Framework, this thesis has developed a new way to examine critical thinking within the context of conceptual learning. The following chapter presents and discusses the research methodology and methods for this thesis in more detail. I justify and describe the techniques used for my data analysis approach that allowed an iterative, focused, but holistic analysis of the data. This process built on each new finding, adding to the analysis and contributing to the construction of a new theoretical framework. Chapters Four, Five and Six present the analysis-discussion and Chapter Seven will conclude.

CHAPTER 3: METHODOLOGY

"The switch from induction to abduction thus requires a gestalt switch in which the theoretical background is foregrounded as a way to set up empirical puzzles."

(S. Timmermans & Tavory, 2012, p. 177)

My research aims, approach and overall direction were subject to many reconsiderations, rethinking and revisions. This research started as a part-time MPhil Education degree course with a broad aim of investigating how and why medical students are supported to become critical practitioners. On conversion to a part-time doctoral degree, the research question narrowed, and new perspectives were introduced from my MPhil coursework. As I learned more about threshold concepts and reflected on my students' learning, I refocused my objective to investigate how critical thinking assists the learning of threshold concepts. To provide a suitable research context, the Quality of Medical Practice curriculum was targeted, specifically the troublesome conceptual nature of evidence-based practice and medical biostatistics. During the design stage prior to the data collection year, the purpose of the study matured and became more theoretical and exploratory, resulting in the final research questions as presented in Figure 1.4 above. This chapter explains the research approach, theoretical framework, study design and methods of this thesis. It begins by providing a reasoning for the methodological paradigms, the qualitative approach, the theoretical framework and analytical techniques adopted to investigate my research questions. Secondly, it outlines the interview and case study series design and presents the research methods used for this doctoral study. Finally, it discusses the study's strengths and limitations.

3.1 RESEARCH METHODOLOGY

The methodological approach for this thesis was chosen to maximise the quality of the data and the research analysis to address the thesis research questions. This section outlines and justifies: the data analysis approach chosen, how Vygotsky's theories and the Threshold Concept Framework (TCF) were employed together for this method and the theory behind the research methods chosen for this thesis.

3.1.1 Theoretical Paradigm

The previous chapters have provided evidence toward the justification of the methodology. As discussed previously, the TCF reflects the constructivist stance of the sphere of higher education where it began. My methodology follows this approach, using relevant educational psychology, philosophy and sociocultural approaches where appropriate. Previous TCF research has used both qualitative and quantitative approaches, but, as demonstrated in the preceding chapter, qualitative methodologies have been used more often for deep analysis of the conceptual processes of the liminal space. In addition, Denzin and Lincoln's description (2003, p. 5) of the qualitative researcher acting as "bricoleur and quilt maker" endorses an approach that allows the researcher to explore, assemble, reassemble and piece together the "representations" that form their research outcomes. So, a qualitative methodology was chosen as the most practical approach to suit this constructivist paradigm and the research intentions. My aim was to carry out an adventurous, yet careful exploration, founded on good research practice through the use of empirical, validated and rigorous qualitative methods.

3.1.2 Data Analysis Theory

A qualitative methodology offered a rich investigation of the data, allowing me to go beyond the surface of student learning and to delve deeper into the complex processes of the student's thinking. A case series study design with enrolment of participants for follow-up across an academic (two-semester) year of study resulted in expected benefits of more depth of analysis, and, additionally, revealed the students' perspective of maturation in their learning, which provided useful data for inter-case comparison. The main limitations of this qualitative analysis approach were the challenge of performing a quality analysis using newly learned theory, and the no-less daunting challenge of having to justify what they perceived as 'less scientific' method to my quantitively-minded colleagues. Other specific limitations are addressed within the third part of this chapter.

Initially, a grounded theory approach was considered as it can be used to build a theoretical framework as data analysis progresses, however, late in the study's preparation I selected abductive analysis as the main approach. This is a relatively new methodology, compared to the well-established inductive grounded methodology (Glaser & Strauss, 1967), but has been advocated for sociological, public health and educational research (S. Timmermans & Tavory, 2012). It is similar to the classic inductive methodology of grounded theory analysis as it iteratively analyses research data whilst emphasising the reflective aspects of analysis and paying attention to surprising and unexpected findings. However, in contrast, abductive analysis uses theory to both stimulate and explore the data (S. Timmermans & Tavory, 2012). The development of abductive analysis as an interpretative qualitative methodology derives from Charles S. Peirce's pragmatist approach to knowledge making-meaning and sign-object interpretation, overlaid by a strong interpretative, social constructionist understanding of the researcher-participant relationship (Ilkka Niiniluoto, 2017). With a nod to Charmaz's (2003) constructivist inductive methodology, S. Timmermans and Tavory advocate a new way to approach data analysis to develop new theories with the meaning-making of theory and knowledge as the central output (Tavory & Timmermans, 2014; S. Timmermans & Tavory, 2012). This abductive approach is more inclusive and subjective than the inductive process, yet it appears to be valid and rigorous. This abductive analysis approach is iteratively reflexive, using acknowledged theoretical frameworks and the researcher(s) own perspective(s), frankly and transparently, in the analysis of the data, to provide an eventual outcome of the results that often outlines a new theory, as depicted below in Figure 3.1.

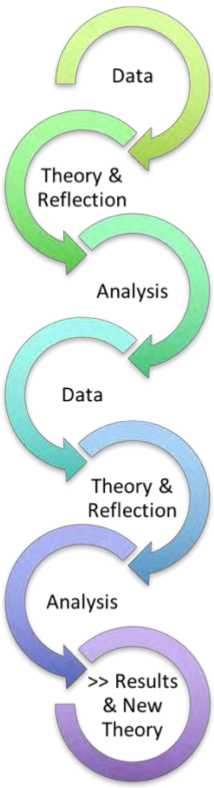

Figure 3.1 Diagram depicting an abductive analysis process

I was introduced to this abductive approach by a colleague who used it for her doctoral thesis on the religious and socio-political intricacies influencing HIV prevention practices in Papua New Guinea. She employed a Foucauldian theoretical approach to analyse her in depth interviews with health workers, reiteratively examining the data thematically with the relevant theories of Foucault to create a new theoretical understanding of the changes that this community was undergoing (Shih, 2015). I was interested in the methodology but concerned as to how rigorous and useful this might be for my research. I discovered that this approach acknowledges Salda a’s (2011) concerns about bringing in theory to analysis, whether it be someone else’s theory as theoretical framework, or our own theoretical and conceptual understandings, acting at the stage of generalising for application back to the population (p. 112). Furthermore, the abductive approach described by S. Timmermans and Tavory (2014) clearly details and utilises the cognitive ownership of the researcher, but carefully avoids Salda a’s pitfall by acknowledging the researcher’s limits and by providing a framework to create generalisable theory, rather than generalisable results.

In pure objectivist, classic grounded theory as applied in inductive methodology, it is seen as a weakness to use the researcher’s tacit knowledge and theoretical understandings for the data analysis (Charmaz, 2006). In contrast, in abductive analysis, the researcher’s socio-cultural and political viewpoints, her theoretical and disciplinary understandings and experiences, are presented as a strength (Charmaz, 2006), as abduction “depends on the researcher’s cultivated position” (S. Timmermans & Tavory, 2012, p. 173). Hence, this method goes beyond most phenomenological or discourse theory approaches in accepting and harnessing the powerful conceptual contribution of the researcher as a source of expertise and knowledge, applying her input reflexively and actively in the mix with the theoretical framework used for the analysis (Charmaz, 2003; Shank, 1998). This is seen as the main strength of this approach and was a key factor in my decision to use this as my main research methodology.

Clarifying the abductive analysis methodological process, S. Timmermans and Tavory (2012, p. 175) state implicitly that this process should aim to foster doubt in order to find uncertainties and detect misfits within the data, and advocate three method steps within a constructivist grounded theory approach: “revisiting the phenomenon,” “defamiliarisation” (derived from grounded theory), and “alternative casing.” Using the first two methods to iteratively examine the data, alongside a comparison with broad theories empowers the researcher to find different ways to understand the data and to conceive new conceptual understandings and theory with which to explain what is seen. This process involves a “switch from induction to abduction” … “a gestalt switch in which the theoretical background is foregrounded as a way to set up empirical puzzles” (S. Timmermans & Tavory, 2012, p. 177). The first two methods derive from grounded theory and have been used in research across many disciplines over many years. The third method, alternative casing, is the ‘thinking through’, using coding, memo-writing and similar analytical methods, of various theoretical and conceptual scenarios to explain the findings from methods 1 and 2 and also “constant comparisons” across the data (S. Timmermans & Tavory, 2012, p. 169). As S. Timmermans and Tavory explain in their manual (2012, p. 177): “Each casing abstracts and highlights different aspects of the phenomenon, rendering it comparable to different phenomena and turning it into a generalization that then can be linked to other fields and theories.” In this way, there is a switching between iterative viewings of the data in order to derive a new theoretical outlook. This abductive approach was well-suited to the exploratory, hypothesis-forming nature of the research questions of this thesis, as well as the reflective approach that I intended to take in my research. Furthermore, Evers and Wu (2006, p. 513) argue that abduction provides the best possible explanation for study data, allowing inference from single case studies to wider phenomena in educational research.

The main limitations of using this approach appear to be similar to those identified for inductive approaches. Most importantly, Charmaz stresses the importance of considering the context of the subjects and data, whilst remembering throughout that data are admittedly a “reconstruction” of the participant experience and not the actual experience (Charmaz, 2003, p. 258). She argues that a constructivist approach is often more fitting to the setting and data, as this approach recognises the interviewer within the research (as expert, teacher, interviewer, researcher). As part of the process, the interviewer is not able to be a strictly objective observer, but preferentially becomes part of the interaction and the reality of the experience of data collecting in the interviews and during the analysis. Hence, the researcher must analyse these “narrative constructions” (Charmaz, 2003, p. 258), with their understanding of the context and using the multiple information sources available, in order to make meaning of it that goes beyond categories to conceptual ideas. Indeed, the researcher’s role as part of the research is explicitly encouraged by Charmaz, as this is an essential step in taking the analysis beyond simple analysis, to the next stage of interpretative synthesis that leads to conceptualisation. She encourages researchers to take their analysis further: “Instead of arresting analysis at the coding stage, researchers can raise their main categories to concepts” (Charmaz, 2014, p. 247). She sees this as an immersive approach; the researcher aiming to “construct rich data by amassing pertinent details” (Charmaz, 2003, p.257); using their experience as teacher and expert, they can take into account the context, physical and emotional responses observed in the data. In listening to or reviewing data, a researcher can appreciate more than just the words; the intention is to hear and feel as closely as possible to the real learning experience presented in these data, although this is admittedly reconstituted through language (Charmaz, 2014).

In summary, an abductive approach was employed for the identification and categorisation of concept types within the data, and for a deeper examination of the critical thinking within the students’ conceptual learning processes. This abductive technique was based upon S. Timmermans and Tavory’s methodology (2014; 2012) with reference to similar constructivist grounded theory approach described by Charmaz (2014). Details of the analytical approach and thematic methods utilised are reported later in this chapter.

3.1.3 Role of Theory in this Research

Theory, the known and the emergent, actively drives research. In this study, theory informed the research questions and steered the choice of methodology, and it was an essential element within the analysis method. Also, theory was one of the key products of this research. In part, the abductive analysis approach was chosen for this research because of the excellent theory and frameworks already published and available on the topic of conceptual learning within the disciplines and in psychological development. I reasoned that my research approach could benefit from bringing accepted theory into the forefront of the analysis, rather than excluding or minimising its effect, as required in classic grounded theory. Abductive theory requires that relevant theories be applied as a lens in analysing the data. For this research the TCF was kept as the fundamental frame of approach. Its general acceptance and high status in higher educational research recommended it, but it had also served me well in my own educational research and so I was cognisant of its effective elements and its flaws. However, for my research the TCF needed strengthening in one major aspect. It had been shown to work well in identifying disciplinary threshold concepts but lacked the full capacity to investigate successfully in the transformational conceptual development area; it needed relevant theory to act alongside it as a theoretical probe.

As discussed in the previous chapter, a Vygotskian perspective was chosen to work with the TCF. Bringing the stronger, established theories of Vygotsky to work with the more recent, structurally robust TCF was sensible. They had potential to complement each other; relevant conceptual frameworks of Vygotskian theory were aligned to the TCF and appeared to fit well, as described below. Consequently, Vygotskian theory became the main thrust of the approach as this developed within the abductive analysis process.

Epistemiological Synergies

At first glance, Vygotsky's theory and the TCF have apparently disparate theoretical approaches, so it is essential to justify how they can work together. Fortunately, the authoritative, dialectic, and revolutionary ideas of Vygotsky from the early twentieth century are greatly able to assist here; among Vygotsky's many educational psychology theories there are several that have striking connections and equivalences with the TCF. Firstly, the language used by the seminal research of both elements is clearly aligned and helps to confirm the synergy of these two approaches. Secondly, there are resemblances and similarities in these theories that interconnect closely enough to be designated as theoretical intersections. During the early stages of the data collection and analysis year, three main theoretical intersections were identified where the Vygotskian and TCF concepts met, cooperated and meshed. These major intersections were recognised initially prior to the commencement of data collection but were further developed as data collection and analysis continued into the final interpretation. The new theoretical frameworks arising from the research were focused around the three major intersections of Vygotskian theory and TCF: 1) conceptual learning as a system; 2) language and thinking; and 3) Vygotsky's zone of proximal development and the TCF liminal space. A surprising, but welcome, finding was that in applying these theoretical approaches as intersections, the core theories appeared to mutually inform and enrich the other, gaining a synergistic, explanatory power that will be discussed within the analysis-discussion chapters.

In terms of research already carried out using Vygotskian theory in the TCF field, there are a few studies published relating to the disciplines of school and higher education fields. However, few researchers have combined these two approaches to the extent of my thesis. Many of the seminal TCF works have touched on the similarities between the ZPD and the liminal space (e.g. Higgs & Cronin, 2013; Ray Land, Meyer, & Smith, 2008; J. A. Timmermans, 2010), and others have used Vygotskian theory to illuminate their ideas and research around transformation and instruction in the ZPD/liminal space (Barton & James, 2017; Land & Meyer, 2011). More research was expected about how and where the ZPD and TCF liminal space intersect. However, this appears overlooked. Furthermore, the TCF liminal space and Vygotskian ZPD have been used separately to investigate critical thinking, but not together. An effective approach for examining student experiences of critical thinking has been used by Wass and colleagues (Wass & Golding, 2014; Wass et al., 2011) where Vygotsky's model of instructional learning has been used skillfully to inform how curriculum scaffolding was achieved. This research doesn't use the TCF or transformative learning frameworks, but specifically examines conceptual learning through a Vygotskian lens. Interestingly, the researchers describe "tacit" concepts (Wass & Golding, 2014, p. 672) and "overarching" concepts (Wass et al., 2011, p. 321), which are classic threshold concept terms, suggesting that they had convergent findings.

Additionally, it was surprising that the TCF research has rarely touched upon Vygotsky's theories of conceptual networking. However, language and semiotics have been partnered with TCF and Vygotsky. Land and his colleagues (2014) used a semiotic approach based on Saussure, in their approach to investigate conceptual learning process. Also, McCulloch and Field (2014, 2015) used Vygotskian discourse theories to expand the theoretical frameworks for teaching of threshold concepts through conversational approaches. These successful studies echo Vygotskian ways of thinking around language and thinking and are discussed as relevant to both the methodological approach and interpretation of the findings. In summary, there is valuable research that has used a combined Vygotskian-TCF approach, but no one has used these together in such depth or looked specifically at the conceptual transformation point of learning with a view to understanding more about how the students' critical thinking assists this process.

In terms of the general methodology, the TCF and Vygotsky's socio-cultural constructivist perspective fit surprisingly well with the abductive approach of S. Timmermans and Tavory (2014). Further, Vygotsky argued strongly for analysis to provide a specific rather than a generalist finding. Indeed, the whole first chapter of Vygotsky's *Thought and Language* (2012, pp. 1–12) is devoted to arguing that, prior to 1934, research in psychology around language and development of consciousness had been restricted to analysing the process into units that are too small. Vygotsky argued that by breaking down these processes, it was possible to lose sight of the dybnamic mechanisms of the processes. This leads to concerns about specificity when applying the findings back from the research situation to the real environment. He used analogy to emphasise his point further:

> The chemical formula for water is equally applicable to the water in a great ocean and to the water in a raindrop. That is why by analyzing the water into its elements we shall get its most general characteristics rather than the individually specific. (Vygotsky, 2012, p. 5)

So, Vygotsky (2012) argues for a holistic approach with attention thrown on the whole "dynamic system," rather than a breaking down of the system into "elements" (pp. 10–11). His rationale for this tactic was simple; elemental analysis is useful but loses the bigger picture, the contextual properties or "specifics" of the process under examination (Vygotsky, 2012, p. 5).

Taking this further, Vygotsky (Vygotsky, 2012, p. 4) advocated the examination of the relevant psychological system as a whole and within its sociocultural and language context in order to avoid generalisations from broken up "verbal thought" that misses analysing the "whole." For example, regarding research into thought and language, Vygotsky says that these should not be isolated into words to examine their relationship but should be studied as a whole system. He argued that it is pointless to study "thoughts thinking themselves" separate to the individual's affect and the origin or consequences of those thoughts, as this fails to discover specifics about the relationship (Vygotsky, 2012, p. 10). Thought and language should be examined as one would intellect and affect; in the context of the individual and their life; as a whole "dynamic system of meaning" (Vygotsky, 2012, pp. 10–11). A more holistic analysis can include the affective and the intellectual as a "unit" so that the individual's "needs, and impulses" are all included in the analysis of how thoughts are generated and also how they result in behaviour, activity and developmental change in the subject (Vygotsky, 2012, p. 11).

This holistic approach to research relates well to the ITCK approach (Meyer & Timmermans, 2016). Therefore, as consciousness, thinking and language appear to be at the root of conceptual learning, I have focused this thesis on the examination of the role of critical thinking and language in the threshold concept liminal space using a holistic a manner as possible. Relevant synergistic elements of Vygotskian theory and the TCF will be presented within the introduction and body of each of the thesis analysis-discussion chapters that follow. Altogether, exploring how Vygotsky's ideas worked with the TCF was one of the most exciting parts of my thesis.

Tension Points

There were some minor tensions between these theoretical approaches that were revealed and dealt with as the research progressed. However, there was one major issue prior to commencement. To authenticate the combination of these theories, it was important to justify Vygotsky's child development psychological theories with the cursorily dissimilar theoretical approaches of the TCF, which were originally developed within higher education disciplines. Essentially, there is a key difference in the learner's age and development stage involved in the original research of these two theories. In this thesis, the research framework is primarily concerned with Vygotsky's language theories and his zone of proximal development (ZPD) as applied to adult learning, disciplinary research and pedagogical practice in higher education. The student participants were all early adult learners, enrolled in an adult learning environment, which fits well with the TCF, as it arose from disciplinary research in the higher education sector (Entwistle, 2003, 2005). However, Vygotsky's relevant educational psychology research was based on primary to secondary school children mostly from around seven years of age. This meant that there could be a substantial issue in terms of the psychological development stages, which is pertinent as my research focuses on conceptual development. Fortunately, previous researchers have argued that, in terms of tackling new knowledge domains, the ontogenesis of learning and intellectual development from child to adult is essentially the same process (Kilgore, 1999; Lantolf & Thorne, 2006).

General educational psychology research tends to argue that adult learning is an extension of the learning processes of the older child, but this advice comes with obvious caveats. According to Mezirow (1990) the learner is more socialised and critically able in terms of reflection as they mature. Also, according to Knowles (1970, 1973), in andragogy the older learner has a more mature self-conception, has gained from their general life and previous learning experiences, and has a strong inclination to learn with self-direction and a more adult orientation towards their learning than a child or teenager. Moreover, it is acknowledged that there is an increasing reluctance to change one's views and conceptual structures as one matures, as aptly stated by Perkins (2010, p. 8): "The threat of change is a threat of *dis-integration*: the disintegration of a particular way of knowing that arises from the disclosure of one's assumptions or from disentangling oneself from that in which one was embedded." Furthermore, it is important to remember that an adult learning environment is very different to the school environment, and that the learning process, especially if transformative, is also believed to differ. As with the ITCK framework, Mezirow (1997) emphasises the affective elements of learning and prior understandings of the older learner, and how these can cause additional difficulties for the wished for epistemological and ontological change of the adult compared to the child learner.

It can be concluded that there are differences between the learning approaches and styles of a child compared to an adult. However, on reviewing Vygotsky's theories, Chaiklin (2003) states the key issue regarding Vygotsky's emphasis on the stage of development is because the "central new-formation produced for a given age period is a consequence of the child's interactions in the social situation of development with relevant psychological functions *that are not yet mature*" (p. 47, emphasis added). Furthermore, Chaiklin (2003, p. 57) explains that Vygotsky meant that the "content and meaning of the zone change" varying with the age and development of the child. So, a natural extension of these principles is that the young undergraduate students (in medicine, students often enter the program at 17-19 years old) and also the more mature students encountered in adult education (e.g. university or college) may have 'psychological functions' (cognitive skills) that are not yet mature or are new to their learning. In addition, to reach this disciplinary ontological and epistemological maturity these students are required to gain an understanding of the key disciplinary academic concepts for the level of degree that they are studying. Therefore, this thesis research considers young and mature adult students using the same psychological terms and theories that Vygotsky derived from his school-age research subjects but takes care to view them as being at a more mature psychological developmental stage. As adult learners they are different on the whole, with higher level psychological functions that can be developed possibly faster or further for the understanding of higher-level transformative academic concepts. With this adjusted principle, this thesis applies Vygotskian educational theories to higher education medical students. Additional adjustments were made at times where deemed necessary for consideration of a very few variances detected between the perspectives of school-based versus adult learning. On the whole the application of Vygotsky's theories to medical students in higher education worked well.

3.1.4 Methodology behind the Study Design

Stage 1. Identification of Disciplinary Threshold Concepts

In the first stage of this study I aimed to identify the key transformative and troublesome concepts in my disciplinary teaching area (Research Question 1 – see Figure 1.4). This was not the major objective of the research but was considered necessary to allow for the investigation of the main research aims. As discussed in the literature review, there was limited research on evidence-based practice in medicine or other health care areas, but more information was available on the fundamentals of conceptual learning, threshold concepts and networks in general statistics, medical statistics and epidemiological approaches to research. I decided to use a simple triangulation technique consulting with students, teacher colleagues and disciplinary experts and clinical professionals in the field. This fits with the ITCK approach published during my data collection year (Meyer & Timmermans, 2016), which recommends a process of consulting previous research and triangulation of data from experts, students and teaching staff to clarify the key and threshold concepts in a discipline. The ITCK approach of "making explicit expert's understanding of the threshold concept" (Meyer & Timmermans, 2017, p. 5) recommends interviewing and reviewing the conceptual nature of the topics that they teach within the discipline, which is essentially how I approached this. I also aimed to analyse the data in terms of the disciplinary ways of thinking that were encouraged through this learning (Research Questions 2 & 3 – see Figure 1.4). For the first stage of my research, the approach taken by Male (2012) for the interviews of experts and focus groups of students was considered appropriate for this element of medicine. Carrying out student surveys was considered but abandoned because faculty had decided on limiting survey-based research of our over-surveyed students at the time of my study.

In the final year of my study, a Delphi-style research project by an international team lead by Bond University, Queensland, published its results presenting main core competencies of Evidence-based Medicine (Albarqouni et al., 2018). These core competencies were not presented with a TCF lens, but their final criteria were very useful for clarifying my research on the EBP threshold concepts, and this research aided my analysis and interpretation, as described in the next chapter.

Stage 2. The Main Research Questions

The first stage of my research identified the main troublesome conceptual areas in my curriculum, the second stage was to answer the main research objective, and so examine how critical thinking assists in the crossing of the liminal space. As the intention was to investigate student conceptual learning in depth, I chose a study design for this stage that utilised recruitment and follow-up of student cases from across the program. This involved interviewing participants immediately after study enrolment and then later in the same year, with cases submitting reflective submissions across the year. This design worked well for identification of threshold concepts for the first research question too. Students had an initial introduction to threshold concepts in the first interview that gave them confidence to identify troublesome learning and specific concepts during the year and in the second interview.

The Vygotsky-TCF theoretical framework was applied abductively to the data collected, for thematic development and using iterative analysis applying it as a lens rather than as a strict framework. My third research question (How does a Vygotskian/TCF framework approach add to the understanding of transformational conceptual learning?) was inherently a product of the abductive process used to answer the second research question (What are the critical thinking skills that enable this troublesome transformational learning for medical students at UNSW?). Chapters Five and Six describe and detail the research process and discuss the main findings.

3.1.5 Methodological Approach to Study Design

The methods used for the interviews and case-study data collection were adapted from salient standard qualitative constructivist approaches to maximise opportunities to generate data in relation to the study's research questions.

Levels of Expertise

This thesis focuses on discovering more about the learning processes that happen at the most difficult point of conceptual learning. In order to achieve this, I recruited and interviewed local academics and UNSW medical students from across the medical program. In recruiting expert teachers, novice and more competent students, my intention was to collect valuable data from across the different stages of learning experience (Kinchin et al., 2008). As experts, academics provide a unique insight into the discipline concepts and the conceptual networks that novice students have little insight into, with the additional benefit of having the appropriate discipline-based and educational language to discuss and explain this in detail (Kinchin et al., 2008; Meyer & Land, 2005). The Dreyfus and Dreyfus five-stage model of expertise (2005) aligns well with current ideas of expertise in the professions, for example it has been used successfully in medicine (Ericsson, 2011), social work (Byrne, 2017) and engineering (Meyer & Timmermans, 2016). Also, this model fits well with Vygotskian ideas of mastery and instruction, and similarly using chess playing in its analogical explanations. Moreover, it has been argued to be a good fit with the TCF by leading TCF researchers (Kinchin et al., 2008; Pearce, 2014). Consequently, this model has been used by other TCF researchers to good effect. For example, robust and thoughtful approaches have been published by Tucker and colleagues following her doctoral thesis research on postgraduate students acquiring expertise in information literacy (Tucker, 2012). She used the five-stage model in the theoretical framework of her thesis to examine her data and found that the TCF assisted the expertise model development as well as her own model of search expertise.

In consideration of this, I tailored the Dreyfus and Dreyfus five-stage model (2005, p. 782) to define the conceptual level of understanding expected for my study participants, as displayed in Table 3.1 below. In this model, experts are recognised as being very different in terms of both their knowledge and power, hence it is of great benefit to interview them early in exploratory research. Bogner et al (2009, p. 2) consider experts as "crystallization points" that can provide better quality data than other data collection methods. Experts have a refined and highest level of disciplinary knowledge than any other source. According to Dreyfus and Dreyfus (2005, p. 787) the not-quite-expert "proficient performer" is "immersed in the world of skillful activity, sees what needs to be done, but *decides,* how to do it." In contrast, the expert has the experience and knowledge to see what needs to be done and has the wherewithal to do this effectively, quickly and almost autonomously (Dreyfus & Dreyfus, 2005).

Table 3.1 Dreyfus & Dreyfus 5-Stage Model levels of expertise
(Based on Dreyfus & Dreyfus, 2005, p. 782)

Stage	Term	Level of Expertise	Dreyfus & Dreyfus (2005)
5	**Expertise**	**Highest level** Competence = high Knowledge = high Experience = wide and deep	"The expert not only sees what needs to be achieved; thanks to a vast repertoire of situational discriminations, he or she also sees immediately how to achieve the goal." (p. 787)
4	**Proficiency**	**Moderate to high** Moderate to high level of knowledge conceptually and holistic approach Competence = medium to high More experience in application of knowledge and skills.	"embodied" experience, so that "intuitive reactions replace reasoned responses" (p. 786) "*sees* what needs to be done, but *decides* how to do it" (p. 787)
3	**Competence**	**Moderate** Moderate level of knowledge Competence = low-medium More experience in using knowledge and skills, adopts plans and perspectives, but still falls back on maxims. A challenging stage emotionally.	"…the competent performer seeks rules and reasoning procedures to decide which plan or perspective to adopt." (p. 784)
2	**Advanced beginner**	**Low-moderate** Low level of knowledge. Competence = low-medium. More involvement in using the knowledge and skills. Uses maxims as basis of performance.	"Instructional maxims can then refer to these new situational aspects, recognized on the basis of experience, as well as to the objectively defined non-situational features recognizable." (p. 783)
1	**Novice**	**Lowest level** Low level of knowledge and competence. Little or no experience of application. Uses simple rules to guide performance but lacks contextual experience.	"The student needs not only the facts but also an understanding of the context in which that information makes sense." (p. 783)

According to this model, experts have a more refined ability when it comes to reacting to situations that demand the input of their conceptual knowledge and skills, that thus allows them to have an "immediate intuitive situational response" (Dreyfus & Dreyfus, 2005, p. 787). Consequently, Dreyfus and Dreyfus agree with Bogner and colleagues (2009), that these experts should be the first group examined in the exploration of conceptual learning. Certainly, the interviewing of academics was the main method used for the original *Decoding the Disciplines* process (Middendorf & Pace, 2004) and has been utilised successfully in many threshold concept studies since 2003 (e.g. Kiley & Wisker, 2009; Thomas et al., 2010). In fact, in-depth interviews appear to provide more detailed and exhaustive information than equivalent questionnaire survey-based or analysis of assessment studies such as Dunne, Low, & Ardington (2003) and Yorke-Barber, Atkinson, Possin, & Woodall (2008). Hence, for my research, interviewing experts was considered the best starting point to identify and examine the nature of the key threshold concepts within my discipline. Making use of their years of experience teaching and researching in their discipline is sensible, as Dreyfus and Dreyfus (2005) explain: "No amount of rules and facts can capture the knowledge an expert has when he or she has stored experience of the actual outcomes of tens of thousands of situations" (p. 788).

At the opposite end of the scale of expertise are the beginners, whom Dreyfus and Dreyfus (2005, p. 783) identify as being novices who are taught rules to get by so that they can then be exposed to "real situations" that can contextualise their nascent understandings to make better sense of what they are observing. Hence, beginners are just important in this study as experts, as their relative naivety in terms of their knowledge and skills makes them useful explorers in terms of identifying the threshold concept liminal spaces that they will freshly encounter. Medical students can be expected to meet many threshold concepts in their early years at university and build on this foundation across the medical program. In addition, as new students they are sometimes braver in facing the challenge and struggle that crossing thresholds entails. Conversely, they may be less aware or able to identify and communicate the processes that they undergo in the liminal space, as they are relatively new to these experiences. This is where interviewing the advanced beginners and more competent students became useful. These learners were actively learning and re-encountering the threshold concepts in practical (e.g. clinical) situations with clinical tutors instructing their skill development and conceptual knowledge. Tutors point out key elements of clinical situations and use examples to illustrate concepts, the student learning actively through authentic involvement in the setting, with the patients and within the subject context. Overall, the Dreyfus and Dreyfus model (2005, p. 782) establishes that examining a broad range of learner (from beginner to expert) is necessary to fully understand the complexity of learning from novice to expert. This concurs well with the current ITCK approach (Meyer & Timmermans, 2016) in terms of triangulating expert, learner and teacher and aligns well with Vygotskian theories linking instruction, development and conceptual systematisation, although there is no cogent detail on expertise (as we now define it) within Vygotsky's published works.

Approach to Data Collection

Interviews are an accepted method of data collection in qualitative research within the constructivist research tradition (Cleland & Durning, 2015, p. 57). Interviews have been utilised in many different disciplines, using varied approaches and being interpreted via different analytical methods (Brinkmann & Kvale, 2014; Miles, Huberman, & Saldana, 2014; Sullivan & Sargeant, 2011). In examining the literature on the conceptual learning of students, it became obvious that useful data for my research aims would need to account for the students' interactions with instructors (teacher and peer), as well as their own internal interactions. These theories build on centuries of experiential research on the benefits of discourse for learning, learning as a conversation (Pask, 1976), and learning and thinking frameworks based on dialogic analysis of Bakhtin, Mead and others (Lysaker & Furuness, 2012; Wells, 2007).

Laurillard (2002) and Vygotsky (1997) stress the importance of the teacher or instructor as central to student learning of concepts and their internal construction of beneficial networks of concepts. In practice, McCulloch and Field (2014) have argued elegantly that these two theorists emphasised separately, but comparably, that conceptual learning is a collaborative process. According to Laurillard (2002) the teacher's understanding of a concept is transmitted to the student via a conversational framework developed to explain the mechanism of the relationship between teacher and student (depicted in Figure 3.2 below). This framework combines and illustrates the interaction of four major components within the process: the teacher's concepts; the teacher's constructed learning environment; the student's concepts; and the student's specific actions (as related to learning tasks, such as a problem-based exercise or a peer discussion).

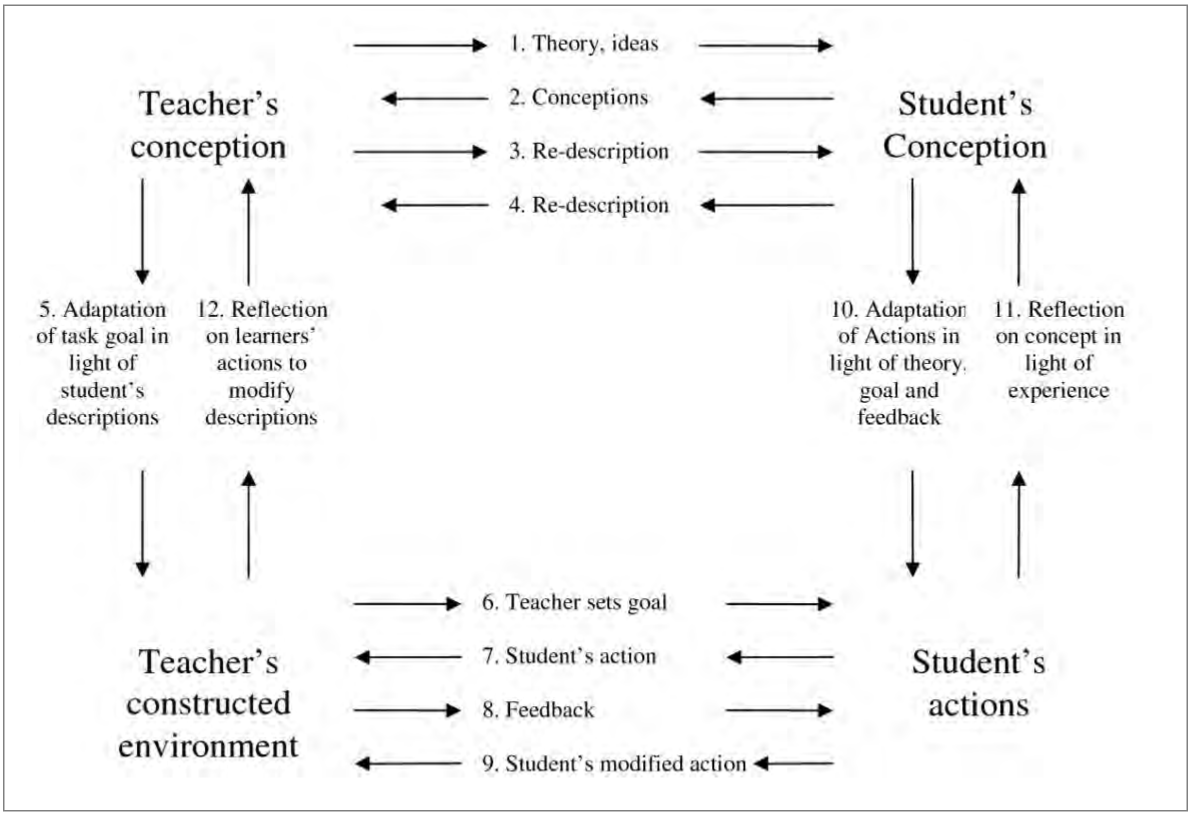

Figure 3.2 Laurillard's Conversational Framework Model
(Source: Wong, Greenhalgh & Lawson, 2010. Creative Commons Attribution 2.0, http://creativecommons.org/licenses/by/2.0)

As a strong advocate of classroom discourse between peers and between learner and instructor, it could be argued that Vygotsky would have been in agreement with the dynamic elements of this framework. McCulloch and Field (2014) present an excellent composite of Vygotsky's ideas with Laurillard's approach in their proposal to support the conceptual learning process of threshold concepts encountered by first year undergraduate language students. They argue strongly for the use of a conversational framework approach to visualise the learning process in terms of this interaction. Hence, examining students' experiences of learner-teacher relationship, and expert/teacher experiences of their dialogue and interactions with students appear to be a sensible approach to data collection and analysis.

Vygotsky's and Laurillard's theories regarding instructional learning approaches agree well with the verbal discourse of research interviews and these were chosen as a suitable vehicle for self-report of the conceptual processes under study. Nevertheless, I planned to extend my approach beyond McCulloch and Field's practice of observation and intervention of teacher-learner interactions as I wished to examine the internal conceptual learning in grappling with threshold concepts. Instead of focusing on the dialogue between the teacher and learner or from peer to peer, I theorised that I could apply a similar theoretical approach to the examination of the conversations that the learner has as their own internal learning dialogue. By asking the participants to describe these internal dialogues and inner speech soon after the pivotal moments of the learning process, I anticipated eavesdropping on the key internal thinking process of their learning.

This approach has been used successfully by Collett et al (2017) using an audio diary method to examine the threshold concept learning in non-medical biosciences curriculum at a UK university medical school. They reported that using these reflective diaries for the identification of the disciplinary threshold concepts was successful and provided some interesting insight into the students' learning experiences of the threshold liminal state and also why they might get stuck in their learning (Collett et al., 2017, p. 100). Other TCF research studies suggest that reflective practice as a data collection tool is quite robust in theory and practice (e.g. Yang, 2009). Additionally, there is evidence that audio and video diaries can capture reflective data on the development of student learning more readily than written diaries (Neve, Stephens, & Collett, 2014; J. Roberts, 2011).

Consequently, I did not plan to observe learner-teacher interactions directly but focused on the reflective recall of interactions and reflections on learning by experts and students. Further, I made a deliberate decision to use reflective journals by the participants as central to the data collection technique for the case study series. In addition, the case study participants were offered the option of audio/video recording their journal contributions. These methods aimed to capture some of the thought processes happening during the crossing of the liminal learning space, revealing the conceptual learning process as remembered and recorded by the student themselves.

Summary of Methodological Approaches

To achieve my research aims, I used a qualitative constructivist methodology, employing a theoretical framework that enabled me to focus on the intricate, intersectional moment of transformation and conceptual learning. Vygotsky, the TCF and other relevant theories were applied to the research data during an abductive analysis approach on data collected using relevant data collection techniques to capture students' inherently subjective learning experiences of transformational moments.

3.2 RESEARCH METHODS

The study design chosen for this thesis provided opportunities for a longitudinal view of students' learning, as well as in-depth examination of the interactive, displayed knowledge of teaching experts with disciplinary understanding. The design consisted of two stages with initial separate explorative interviews with experts and students, followed by a case study series approach; a longitudinal follow-up of medical students using interviews and journal recording at self-chosen key points in learning development. Details are provided below regarding the research methods and processes undertaken in this study. Emphasis has been provided on the data collection and detail regarding the steps taken during the coding and analysis. This was done purposely, in consideration of the abductive analytical approach taken, to provide further insight into how these research processes contributed to the interpretation of the data and the thesis recommendations.

3.2.1 Research Setting

The University of New South Wales (UNSW) is a large higher education institution, supported by public funds from the Australian Government. The Faculty of Medicine and has two major undergraduate programs: medicine and exercise physiology. Each year there is an excess of 3,500 applicants for a total of ~200 standard medical program entry places and 70 indigenous and rural students. This student intake consists of a large proportion of selective school graduates, and international students as well. The chosen students are an elite group with "the median ATAR for entry … always greater than 99.60" (UNSW Medicine, 2016). These students have done very well at school, often gaining the school dux award or finishing around the top of the state HSC subject ranks.

On entry into the medical program, these students are under tremendous pressure to succeed. The stakes are high as it is expensive to repeat courses. In addition, it is well known that medical students tend to be perfectionists, hate to fail and find it emotionally traumatic when they meet difficulty – more so maybe than students who struggled more at school and have learned to work through these moments of crisis (Dyrbye, Thomas, & Shanafelt, 2006). Furthermore, they tend to be less healthy and less mentally stable than their non-medical student counterparts (K. J. Moffat, McConnachie, Ross, & Morrison, 2004). Depression, anxiety and suicide are not uncommon in medical students with studies showing a prevalence of depression and anxiety of up to 66.5% in studies from English-speaking, medical schools outside of North America (Hope & Henderson, 2014, pp. 48–49); and a pooled prevalence estimate of 27.2% of students screening positive for depression was revealed by a systematic review by Rotenstein, Ramos, Torre, et al (2016, 2216). Examining the causes of this is difficult as there is no recent published longitudinal study, however, there are indications that academic performance is related to both anxiety and depression. Students with lower grades are more anxious, and top students have a lower depression score (Yusoff et al., 2013, p. 131). In addition, the "mastering of knowledge" has been linked to depression and anxiety (K. J. Moffat et al., 2004, p. 483). Bore, Kelly and Nair (2016) found that there were many risk factors for psychological distress, but the major modelled effects were lower emotional resilience and poor self-control with lack of social support contributing significantly to distress.

Consequently, student well-being is being carefully examined by medical schools across the world with programs being developed to prevent issues and support students with problems, for example curricular changes (K. J. Moffat et al., 2004), and the introduction of mental health practices (Warnecke, Quinn, Ogden, Towle, & Nelson, 2011). This significant, under examined factor of academic pressure and impact of learning difficulties on mental health at medical schools was part of the motivation for the initiation of this research and was considered when designing the study to ensure careful elucidation of the student participants' emotions, and for the protection of their well-being.

Regarding the disciplinary context, the medical program is a 6-year curriculum that fully integrates medical and clinical sciences with skills-based elements including my own discipline of Quality of Medical Practice, which has been detailed above. Stage 1 of this research focused on threshold concept identification within this discipline, specifically focusing on evidence-based practice and medical biostatistics. Stage two of the study, the case series, was less strict, with students reflecting on a wider range of conceptual learning in many of their courses including medical sciences and clinical practice.

3.2.2 Study Design: Data Sources

Study Participants

This research focuses on discovering a new understanding of the internal processes that occur at the most difficult point of conceptual learning. In order to achieve this, I recruited and interviewed local academics and UNSW medical students. In recruiting the expert and students (from novice to intermediate and higher-level learners) for group interviews, I planned to collect valuable data from across the different stages of learning from experience, as explained by Kinchin, Cabot and Hay (2008) and as recommended by Dreyfus and Dreyfus (2005), discussed above. As experts, academics were expected to provide a unique insight into the discipline concepts and the conceptual networks that novice students have little insight into, with the additional benefit of having the appropriate discipline-based and educational language for disciplinary discourse (Kinchin, Cabot, & Hay, 2008; Meyer & Land, 2005). To assist with the data analysis, I defined the conceptual level of understanding and expertise of participants according to the curricular elements and level of understanding expected for that level of student/lecturer, as presented in Table 3.2. This framework was used explicitly in the design, analysis and interpretation steps of this study.

Participants

The expert teaching staff recruited were either academics based in UNSW Medicine and clinically trained teaching staff from clinical schools in the allied teaching hospitals. The medically trained staff mostly had no formal teacher training, and campus-based staff had variable levels of training, from university-level foundations of learning and teaching up to Master of Medical Education. This is not an unusual finding in medical education, and, especially in clinical teaching; these doctors are considered as "experts in what they teach" rather than "how they teach" (MacDougall & Drummond, 2005, p. 1213). All the expert participants had a decade or more of teaching experience. All expert participants had been assessors and involved in carrying out curricular-design and development, either in the medical program at UNSW or for public health Master level degree courses or for professional level curricula.

Most of the experts recruited for interview had heard about the threshold concept framework, as this has been widely propagated across faculty and the university as an effective teaching strategy. However, none of the experts had carried out specific research on the topic. In addition, few of these experts had experience of qualitative research methods. In contrast, the students researched in the study were all recruited from the current medical program and had been introduced directly to the basic idea of threshold concepts as I present the evidence-based practice and statistics threshold concepts explicitly in my Quality of Medical Practice lecture series.

Table 3.2 Levels of conceptual expertise in undergraduate medicine at UNSW (Derived from Dreyfus & Dreyfus, 2005)

Participant	Conceptual Level of Understanding	Justification
Medical faculty academic and clinical lecturers	**High = Expert** Highest level knowledge and skill Competence = high Experience = wide and deep	Academic or conjoint position. Degrees in a relevant discipline (e.g. statistics, medicine, medical education) Experience in teaching and / or research. Professional practitioner.
Post-internship medical graduates, Masters and PhD students or other experienced postgraduate students/researchers	**Medium to high = Proficient** Moderate – high level of knowledge conceptually and holistic approach Competence = medium to high More experience in handling, analysing/ interpreting data e.g. > 2 years of application of knowledge	Medical degree. Doctoral level research Primary degree in Public health or medicine or medical or biosciences. Varied statistical understanding depending on learning and experience.
Year 1 and 2 medical interns, senior level medical students: Phase 2, 4th year students (research year) or Phase 3 (final 2 clinical years)	**Medium = Competent** Moderate level of knowledge conceptually Competence = low-medium Have had more experience and time to apply knowledge than Phase 1 students by >2 years	Finalising their 4th year research or in Phase 3 of the medical program having completed the research year. Has applied and built on conceptual knowledge from Phases 1 & 2. 1st or 2nd year interns, post-graduation. Beginning to learn proficiency.
Middle level student Phase 2 **3rd year (clinical coursework)**	**Low to medium = Advanced beginner** Low - Moderate level of knowledge Competence = low-medium More experience/ time to apply knowledge than Phase 1 students by 1-2 years	Understands the basic medical and QMP concepts but has not had much chance to apply these and/or consolidate this learning with practical application.
Phase 1 Year 2	**Low+ = 2nd year beginner (Novice)** Low + level of knowledge Competence = none - low Little/ no experience, poor understanding	Have studied one year of general medical subjects and QMP so may understand some but not all of the key Threshold Concepts. Have had little or no opportunity to put this into practice in clinical situation.
Phase 1 Year 1	**Zero – low = Absolute beginner (Novice)** None – low level of knowledge Competence = very low - low Little/no experience, v poor understanding	Essentially a novice but previous learning (school/other degree) may provide some conceptual understanding.

Recruitment Methods

The experts were well known to me as they are colleagues at UNSW. They were approached directly by an initial email request with a follow up phone call or brief meeting. The student participants for the focus group and case series were recruited by an advertisement placed as an announcement in relevant Moodle courses during March and April 2016. An automatic email was sent to each student via his or her UNSW email address when the announcement was posted. For students recruited for the case series research, care was taken to ensure that they understood the nature of the research study and the implications in terms of time and required meetings. No pressure was placed on any potential participants to take part, and no benefits were used as inducement (except for pizza provided to the focus group as this was after normal university teaching hours). Consent was obtained as per UNSW protocol, following an initial meeting to discuss the research (as described in the Ethics section below). See Table 3.3 below.

Table 3.3 Summary Table of Participants

Job title/Student year	**Participant group** **Gender**	**Expertise level**
Medical faculty academic	Expert interviewee 3 (1 female, 2 male)	High = Expert
Clinical academic or clinician	Expert interviewee 4 (1 female, 3 male)	High = Expert
Senior level medical students Years 4-6	1 Case study participant: female, 5th year 1 Focus group participant: female, 4th year	Medium = Competent
Middle level student Phase 2 Year 3	2 Case study participants: 1 female, 1 male 1 Focus group participant: male	Low to medium = Advanced beginner
Phase 1 Year 2	1 Case study participant: male 0 Focus group participants	Low+ = 2nd year beginner (Novice)
Phase 1 Year 1	4 Case study participants: all male 3 Focus group participants: all male	Zero – low = Absolute beginner (Novice)

Expert Participants

Seven experts were recruited from UNSW Medicine. The first expert recruited was interviewed alone as he was not available later on when the interviews were planned. A further six experts were recruited and paired for interview with an academic from a similar or compatible discipline and/or profession. All participants were acquaintances and colleagues. Experts were consented as per the standard UNSW protocol and provided with a list of possible interview questions (Appendix 3.1), definitions of threshold concepts and critical thinking skills (Appendix 3.2). Appendix 3.3 summarises the expertise level of each expert and shows the pairings used.

Focus Group Participants

Six students responded to the recruitment announcements for the focus group, but one was unable to attend at the last minute. They comprised four male students and one female student, all enrolled and attending classes at the main campus. Two were higher-level students: 3rd year (male) and 4th year students (female). The other three participants were all first-year male students.

Case Study Participants

Eight students (2 female and 6 male) from the medical program responded to the case series recruitment email and all were recruited. One of these volunteers was categorised at a level of *competent* expertise (an expected higher-level understanding of the discipline threshold concepts under study). She was one of the 2 female students recruited and was in her fifth year (Phase 3 of the program), enrolled at a rural campus. Two Sydney-based third-year medical students (one female, one male) were recruited from Phase 2 of the medical program (considered to be *advanced beginner* level). The remaining five students were recruited from Phase 1 of the medical program at the Sydney campus and all were male. Of these, four were first-year students and one was a second-year student. All were categorised as *novices/beginners* as none had entered the program with knowledge or experience beyond basic school-level statistics and no previous healthcare training. They were judged unlikely to fully understand the majority of the threshold concepts expected to be encountered and tackled by students during Phase 1 of the medical program.

Unfortunately, no fourth-year medical students or sixth-year students responded to the recruitment emails. This is likely due to the increased pressure of work encountered in these years (4th year is the research year and 6th year is the final year of the medical program). The third-year student dropped out from the follow-up during August reporting that pressure of academic work meant that he could not continue. He did not send any further journal submissions and did not have a final interview. Two Phase 1 student case participants took part in the focus group as well as the case series research. One student case (first year) did not respond to any email requests for journal reflection submissions and did not reply to the second interview request. Overall, these eight cases were considered a reasonable spread of student level of expertise from beginner to competent, although it would have been advantageous to have some more competent student participants. All recruited case study students were provided with same definitions and visual aids (Appendix 3.2) as the other participants and also were provided with detailed verbal and written instructions explaining the case series process (Appendix 3.4).

3.2.3 Study Design: Data Collection Methods and Tools

Various data collection methods and tools were used for the different participant groups and at different times for the case series research.

Interviews

As this study was exploratory and constructivist in approach, the mainstay of the data collection method was semi-structured, in-depth interviews; questions were relatively open-ended and used as a structure rather than as a strict list (See Appendix 3.1) (Male, 2012). From this constructivist perspective, the interviews were designed to allow me to reflect on and interpret the interview data using my analysis technique, but with the understanding that the resultant theorisation would be my interpretation of the participants' experience (Charmaz, 2014, p. 239). To enable this process, clear interview techniques were employed as recommended by qualitative methods training and literature (Hesse-Biber & Leavy, 2011). Specific advice was sought from relevant, expert sources on interviewing and analysing data from specific participant groups, including: experts (Bogner et al., 2009), focus groups (Kitzinger, 1995; Polkinghorne, 2005), and student cases (Ayres, Kavanaugh, & Knafl, 2003; Polkinghorne, 2005; Schön, 1991). Direct questioning was restricted to confirm the interviewer's understanding of the participants' comments. Probing questions were used where necessary to clarify the interviewer's understanding and clarify meaning in order to "stay close to the lived experience" (Starks & Trinidad, 2007, p. 1375). Details are provided below for each group of participants regarding the decisions made for the specific approaches eventually taken for the data collection.

a. Expert Interviews

A paired interview method was chosen for gaining insight from the experts in the field, especially to allow for collaboration and discussion between each pair of experts in order to better identify the key threshold concepts in the discipline. In interviewing pairs of similar experts together, I aimed to encourage interactions that would provide useful data for analysis (Bogner et al., 2009). The reasoning for this was based on the group interview principle that interaction between the interviewees would provide productive elements above and beyond that provided by individual responses from a straight issue-oriented interview (Kitzinger, 1995). However, a note of caution should be applied to possible interaction effects as these could affect the data collectable from these interviews in both a positive and negative way. Therefore, attention was placed on the interpretation of these effects as an element of the process, rather than as data variables or themes in their own right (Bogner, Beate, & Menz, 2009, p. 45).

b. Group Interviews

For interviewing the medical students regarding the identification of threshold concepts, a focus group approach was chosen with a view to encouraging students to talk with more freedom than if they are individually interviewed (Brinkmann & Kvale, 2014, p.101). In addition, the group nature of this interview was intended to create spontaneous discursive dialogue that could reveal more information on the interview topics and found to be useful especially for exploratory research (Kitzinger, 1995). Furthermore, as these were medical students invited to discuss curricular matters with me (one of their lecturers), it was hoped that the group nature of the interview would be less threatening (Male, 2012). This was especially important considering the troublesome nature of the threshold concept learning process and possible anxieties this can produce in the learner, and also issues relating to communicating something that is not yet well understood. Moreover, I hoped that the group situation would encourage students to share and compare their experiences which would help in the identification of possible threshold concepts and emotions arising from these learning experiences. Similarly, the group interactions were expected to be useful in stimulating useful discourse around the critical thinking skills that these students feel are useful for or hinder their conceptual learning. However, it has been suggested that a group interview format may also create a more "chaotic" interview and hence be harder to guide participants towards the topics of most interest (Brinkmann & Kvale, 2014, p.101).

The usual UNSW focus group ethic protocols were followed: the maximum group size of 10 participants was not exceeded and the maximum running time of 90 minutes was adhered to. Definitions of threshold concepts and critical thinking skills were provided to the participants (as for the expert participants). Guiding questions were employed from a prepared interview outline and probing questions were also utilised (see Appendix 3.1). To ensure careful control over the interview process, there were two researchers present for the focus group interview. I was the lead interviewer, guiding the direction of the discussion using question prompts, whilst my colleague concentrated on taking notes whilst monitoring the questions and discussions arising.

c. Case Series Interviews

Each individual student participant was interviewed early in Semester 1 of 2016 and then again later in the year, mid-way through Semester 2. A semi-structured approach was used with an interview guide and lines of inquiry being thought out prior. These were used by the interviewer (the author) in order to guide the interview and discover the information sought (Hesse-Biber & Leavy, 2011). The aim of the interviews was to explore with each student their understanding of threshold concepts and what happens in terms of critical thinking at crucial learning moments that they could recall from memory. In addition, there were opportunities within these interviews to test the understanding of the threshold concepts and to assist students in their understanding of it. Prior to the data collection, I conjectured that some of these interviews could develop into learning moments themselves. I was comfortable that this should happen because, as described earlier in this chapter, I am keen to analyse the conversational element of this learning and hence using interviews as a stimulus for this to occur seemed viable and reasonable. However, to ensure that the participants were comfortable with this happening I consented for this verbally at the beginning of each interview. In addition, I checked at the end of the interview that students agreed for all the data to be used for the analysis.

Interview Process and Recording Methods

All interviews were held in a quiet, private room. The interviews commenced with a short introduction and outline of the process to be taken. There was a brief reiteration of the written consent (already obtained) and interviewee(s) were asked if they had any questions.

All case series interviews were kept to around 60 minutes in length. Expert interviews were all over 90 minutes in length (maximum 105 minutes). The individual and paired interviews were in-depth, interviews, using a loose semi-structured interview plan, with open questioning and occasional prompts to encourage discussion that drew out meaning and explanation, as discussed above. For the experts and focus group interviews, I commenced the interview with a short explanation of the theory of threshold concepts and liminal space. It was decided to provide a print copy to interview participants of the threshold concepts definitions by Meyer and Land (2003), as well as a formal definition of critical thinking, based on the international consensus statement led by Facione (1990) (see Appendix 3.2). Initially I was concerned that I might be 'giving too much away' by showing these definitions so early in the conversation, but these proved to be useful tools, offering a good starting point for the conversation into the troublesome nature of learning and how we think within that process, without being derivative or prescriptive. Some participants used these as reference points within the interviews, but mostly the interviews centred on their own understanding of threshold concepts and critical thinking.

I used appropriate questions from a pre-determined semi-structured list to initiate discussion in response to the dialogue with the participant, for example: "Can you identify the key stumbling blocks in the learning of statistics in undergraduate medicine?" A non-judgmental approach was openly taken with the information divulged, and interviewees were encouraged to call a halt or take a rest if needed. The interviews with experts were more like conversations in that they were very discursive, non-argumentative. I aimed to make participants comfortable enough to take the lead in these conversations, especially in the expert paired interviews. As the interviewer, I asked clarifying questions when necessary but also took part in the discussion, as and when I thought this was appropriate.

Each interview was recorded using a digital phone device with a backup digital recording device. In addition, I took copious notes, a habit picked up from clinical practice. I prefer to write notes as mind-maps, concept-maps and diagrams. Hence, I searched for a recording system that would enable quick and easy note-taking, allow for flow of thoughts and ideas to be clearly noted, but not distract me or interviewees from the conversational flow. A themed prompt grid (which I have named the 'Jens grid' after Jens J. Hansen (2016) who recommended it to me) was used as an interview guide and for recording the interview process. This was a single sheet of paper with a 3x3 grid table of pre-written topics/themes for each interview type (see Appendix 3.5). In addition, it was deemed important to record where and when participant(s) offered incidental key pieces of information, and to record key points of the interview to act as way markers. These notes also recorded the flow of the interview through expected and unexpected themes (Hesse-Biber & Leavy, 2011), and I used arrows and time markers which converted them into time-based note-maps. These notes were useful in analysing the flow of interviews as they happened and helped me to ensure that expected themes and key topics were touched upon (as deemed necessary at the time).

The final version of each grid tracked the course of the conversation of the participant(s) through the various themes, thus providing a combined written-visual record of the interview. The Jens grid of each interview was examined in parallel to listening to the recording and/or reading the transcript during the data analysis. So, a visual mapping of the learning process, using the Jens grids, was a useful data source for interview analysis. Additionally, concept-maps were used to assist in feeding back to case series students regarding the research findings. This process was part of the iterative abductive technique to case and compare interpretations of the journal reflections and coding categories derived from across all case series participants.

Collecting Reflective Data

Mezirow and followers of the 'transformative learning' academic set have written widely on the relationship between reflective practice and transformation, as detailed earlier in Chapter Two. Within higher education, reflective practice is deemed an essential part of curricular approach (Boud & Walker, 1998; Mezirow, 1981, 1990, 1997; Schön, 1991). Similarly, reflection has been used successfully employed across many disciplines as a qualitative data collection method, where the intimate, critical reflection of the participant is sought in order to gain insight into processes and experiences. For example, in psychology journals have used effectively to collect self-reflections (Polkinghorne, 2005). Limitations of this method revolve around the issues of personal recall and how to express this to another person in language, which therefore similarly would be expected to affect interview, questionnaire and survey-based data collection (Polkinghorne, 2005, p. 138).

Despite these concerns, reflective practice using various data collection methods is a becoming a well-recognised and successful learning and assessment activity for higher education research. It is increasingly used in threshold concept research, with an emphasis on simultaneous recording of the reflection (reflection-in-practice). The methods used vary, depending on the study design, but all are essentially collating self-reflection information, for example: written diaries (Berry, Depaepe, & Van Driel, 2016; Kinchin & Miller, 2012; Nicholls, 2015); and audio (Collett et al., 2017) or video recordings (J. Roberts, 2011). The combination of reflection for transformation and reflection around the learning moments of threshold concepts, recommends journal-keeping as a useful method for capturing the learning experiences of the student cases. Participants in this study were encouraged to use whichever method worked best for them (written, audio or video).

Furthermore, the method of concept-mapping has been used as a method of studying, and as a useful method of recording and analysing learning experiences (Kinchin et al., 2008; Kinchin, Cabot, Kobus, & Woolford, 2011; Thomas et al., 2010). In these studies, the researcher and /or participants used a visual mapping technique to learn with or record and/ or analyse their approach to learning. Kinchin, Cabot and Hay (2008) strongly advocate using concept mapping to make visible the hidden elements of learning within the liminal space. They went on to demonstrate how this method worked for their teaching purposes (Kinchin et al., 2010). Their reasoning for using visualisation as a research method, is that experts no longer see their journey through the liminal space, as they are too experienced at traversing the route to be able to remember it, whereas novices find they have not the words to communicate their experience, as they haven't enough experience of it and their disciplinary language knowledge is similarly restricted. For their research, they used a conceptual mapping teaching approach, succeeding to illuminate some of the concepts, knowledge pathways and personal navigations which lead to individual conceptual understanding (Kinchin et al., 2008).

This method of collecting data appears powerful, but it is important to recognise that reading and understanding this visual mapping as a form of communication is not an aptitude that everyone has or can develop well. Hence, in this study, case participants were encouraged to choose this method for their journal reflection, if they believed that it could work for them. Personally, as visual conceptualisation is one of my strengths, I used this technique for my research for memo taking, note taking and reflection, and as mentioned I used concept maps as part of the Jens grid notes and also concept maps to feedback interpretations into case participants later in the study.

Journal Records

Each student case was asked to keep a journal to record their experiences and specifically their process of understanding. They recorded observations when they encountered an identified threshold concepts or related concepts, and especially if they got stuck in their learning, or troubled by any conceptual learning. To cater to personal preferences, students were encouraged to mix and match whichever approaches they wished to use to record their electronic reflective portfolio 'journal': written text, voice or video recording, creation of concept maps (hand written or via dedicated software). Email reminders were sent to each student on a fortnightly basis during academic term time, asking each student to send in a journal updates (all material they wish to share with the researcher).

The second case interview later in the year was used to summarise, clarify and further examine the students' regular journal observations, which followed the abductive analysis approach assisted by some "across-case" strategies as outlined by Ayres, Kavanaugh and Knafl (2003, pp. 873-4). Additional data were collected in these second interviews by using question prompts derived from analysis of the earlier Stage 1 data analysis of the experts and focus groups, as well as analysis so far for the case study series data. For example, the audio and Jens grid for each case's first interview was referred to prior to, in order to remind the me of the content and direction of that initial data. I made note of any potential gaps in my data or interpretation and noticed if there were areas that needed clarification or further depth. Further semi-structured questioning along these topic lines was very helpful in furthering the abductive analysis. Also, this final interview was useful for comparative analysis process across the cases regarding the theme coding so far. It was possible at this stage to compare each students' experience with data categories and emerging theories derived from coding analysis of other participants' journals. This approach carefully followed the iterative abductive method as described by Tavory and Timmermans (2014).

Data Handling and Organisation

The data were imported into NVIVO (for Mac versions 11.1.1-11.4.3) as appropriate: audio files and transcriptions were linked for later editing and coding; concept maps were scanned and imported as image and Microsoft Word files where possible. In NVIVO, the data was organised by case classification into the groups: case interview 1 (8 audios with transcripts); case interview 2 (6 audio recordings with transcripts); case journals by case (27 separate reflective submissions containing over 40 individual dated items); expert interviews (4 audio recordings with transcripts) and the focus group (1 audio recording with transcript). In addition, my memos and reflections were added as NVIVO memos.

Analysis and supervision notes and information provided to participants were also added to the database within the internal sources area. In all, this provided a large amount of high-quality data, despite the relatively small number of participants in the study.

Transcription of Data

The recordings were transcribed using a professional and secure transcription company and were imported into NVIVO. In preparation for the analysis I de-identified the participants, maintaining just the case number for identification. There was a total of 19 interviews: a total of over 23 hours of audio recording, of which, more than 16 audio-hours were from case series interviews. All recordings were handled confidentially, and the devices and downloaded sound files kept securely. Transcription by external means was considered necessary due to time, work and skill limitations. This process is recognised as a potential point of loss of data, but in the case of abductive analysis the more times you can re-view the data, the better (Tavory & Timmermans, 2014). Thus, this was a positive part of the analysis process, as the more removed the researcher is from the data, the easier it is to inscribe, alienate oneself from the data and therefore problematise and case the theory better. Furthermore, the more times the data are re-viewed, the more the data can be revisited, defamiliarised and examined for alternative casing. However, to limit transcription errors initially and to re-experience the interviews I listened to every interview audio-recording as I went through the transcriptions, using this as an opportunity to learn more from the interview and also to check accuracy of each transcription and to add in emphasis where appropriate. There were some issues with the audio quality (loudness and clarity) at times. In addition, there was a variation in the quality of the transcribers, and some had more difficulty than others with the audio sound level and quality and participant accents. There were moments of over-talking, so a few phrases were missed. Nevertheless, on transcripts were mostly good quality and I was able to decipher and clarify data if necessary.

3.2.4 Research Analysis Processes

My primary research aim was to ascertain the key points of difficulty for student learning of threshold concepts in the UNSW medicine program and the critical thinking processes that this entailed. An abductive analysis approach was applied to the data collected from the interviews and focus groups, using the various theoretical models discussed as a lens for developing a more focused framework. The language used, and conversational elements of the data was at all times considered and carefully analysed, both as a whole and as its elements and themes. My reasoning for this dual approach was that language is key to student learning of concepts, as previously discussed in terms of student-instructor interactions as per Laurillard (2002). To gain understanding as learners we think out loud, we write in words, draw in images, or compute or elaborate mathematically in a kind of thinking monologue. Also, we talk (within dialogue) to our learning peers, and discuss and debate our understanding with teachers, instructors and experts. In addition, through all of these processes we are debating, deliberating and internally monitoring our approach and outcomes using our inner voice. As explored above, taking care with the language revealed in the data was intended to lend an overall view of what the data meant. As seen in discourse analysis, I wanted specifically to discover the implicit as well as the explicit meanings expressed by the participants in the language they used in the interviews and the case journals, and moreover, I wanted to relate this to the knowledge, context and social constructions underlying this whole (Paltridge, 2006).

Therefore, the transcribed data were carefully analysed line-by-line to create appropriate categories as coding themes, which were used for further analysis and detailed comparison to reveal the reconstituted experience of the student at troublesome learning points. Care was also taken to view the data as narrative, looking beyond phrases to reveal the whole meaning of the interviews as conversational dialogue in order to see the larger picture as well as the detail (Hesse-Biber & Leavy, 2011).

All analysis was primarily processed manually via NVIVO software for Mac using the coding analysis and annotation tools, but hand-written notebooks were used to summarise thematic and coding advances and details along the way, and memos created of these as analytical summaries for each step in the analysis (i.e. for each case transcript analysed). In addition, across the whole process of this research, I used drawings, mind-maps and concept-maps created on large plain paper notebooks as conceptual learning aids for the interpretation. This process was invaluable to my own conceptual journey in understanding both qualitative research and also for getting to grips with the methodology, the theory, the data and the intersections. Privacy and confidentially of data storage and handling are detailed in the Ethics section below. The following detail is provided to show how the abductive analysis was carried out with the aim of answering the research questions (see Figure 1.4).

Waves of Abductive Analysis

The first step in the analysis involved identifying and delineating the key troublesome concepts encountered in student learning across the medical program. This then enabled the application of the abductive analysis approach in the interview and journal data around these troublesome concepts and networks. The abductive approach allowed categorical themes to arise from the data with the theoretical assistance of the threshold concept framework, with a Vygotskian perspective and other relevant theories of conceptual learning applied where appropriate. Concept categories were generated from within the data with the assistance of the known theory and my experience of teaching these concepts to multiple student cohorts during the previous 13 years. Reiterative analysis was carried out across all the expert and student interviews, and the case students' reflective journals developing coding themes for the concepts and recording analysis that signposted key topics areas and indicated relevant data concept areas. Two further waves of analysis were carried out, increasingly deeply focussed on these thematic areas and using the Vygotskian/TCF framework as a lens. This involved further examination of detail in the participants' reflections on those troublesome points of learning in order to identify the conceptual elements and also to examine the struggle and transformation experienced in these learning moments (these deeper analysis phases contributed to analysis for the second and third research questions). A final wave of abductive analysis focussed more specifically on the integration of the concepts fit together in the mind of the learner; the formation of networks and complex concepts, and any disciplinary differences that were exposed by this process. Matrices were used for the coding themes and further categorisation of the concepts. These matrices (included as appendices in Chapter Four) were discussed with supervisors and experts to tease out finer points of distinction and create clear naming/labelling of these concepts within the categories and also to clarify further how they appeared to link together.

This first research step answered the first research question, which assisted in directing where the abductive analysis process should focus for answering the two remaining research questions, relating to the examination of the critical thinking skills being used by the students to aid their learning in these troublesome areas, and the evaluation of the Vygotskian/TCF lens for conceptual learning. Throughout this research stage, my analysis drew on this intersection to generate a new way of thinking about transformative conceptual learning and to clarify the implications that this has for teaching critical thinking to aid student learning in medical higher education. As mentioned above, some of this data analysis is not presented in Chapter Four in detail but was taken forward into further analysis and presented in later chapters.

Abductive Techniques

An iterative abductive approach as detailed by Tavory and Timmermans (2014) was taken with the coding and iterative comparative analysis adapted from stepped grounded analysis methods as set out by Charmaz (2003). Key coding processes used emphasised the grounded approach – i.e. making comparisons by line-by-line coding and using sensitising concepts as departure points from which to study detail seen in the data. An iterative comparative analysis was performed across the data collected from all interviews for each research question separately: across different participants; within each individual's data; for incidents noted in interviews; and within and across categories created through thematic analysis. The techniques used for this process included: "dimensionalising," axial coding, selective and focused coding, leading to the formation of conditional matrices as analytical diagrams (Charmaz, 2003, p. 260; Starks & Trinidad, 2007, p. 1376). In addition, commitment was taken to examine data originating as "overt actions / statements" as well as the "implicit meanings and underlying assumptions" made by participants, in order to ensure that both the obvious and less obvious themes arising from within these data were uncovered (Charmaz, 2003, p. 260). Furthermore, memo-writing (including concept-mapping) is encouraged specifically. Charmaz recommends this technique "to spark out thinking" and as an analytical tool to "elaborate processes, assumptions and actions" that can otherwise remain unexplored in simple coding of themes (Charmaz, 2003, p. 261). The key steps from the full process as described by Tavory and Timmermans (Tavory & Timmermans, 2014) is presented in Figure 3.3 (below). The cyclical nature of my part-time research perversely helped it by facilitating these processes, (e.g. revisiting and defamiliarising). However, the start-stop-start nature of analysis hindered the mental process of linking up of the interpretation and made detailed examination and interpretation less easy. Casing with theories was done by cross-case comparison and data interrogation, and also going back to experts with key findings for further discussion.

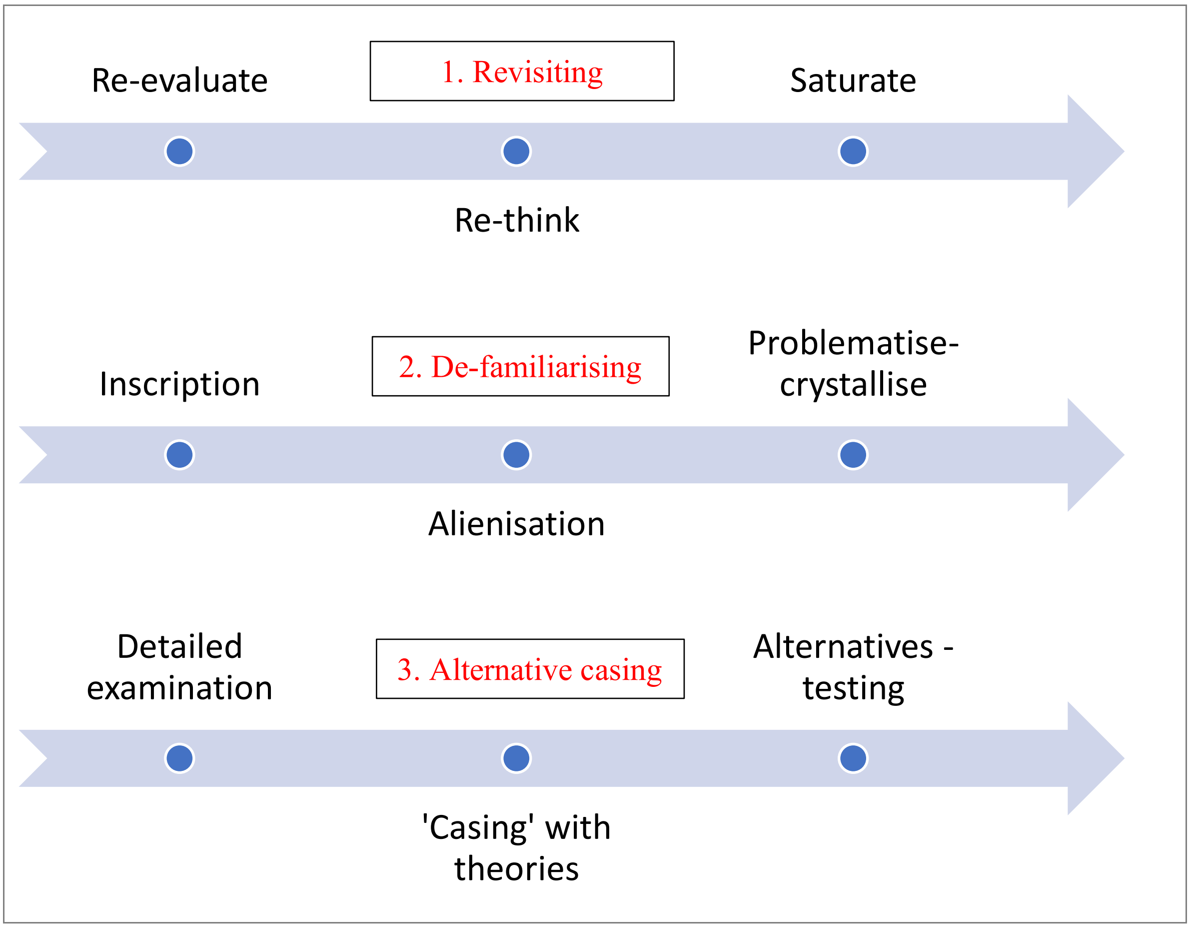

Figure 3.3 Key abductive analysis steps
(According to Tavory & Timmermans, 2014)

Technically, an iterative, open approach to coding and recoding was taken, but narrative and conversation was also examined as a whole where this was deemed appropriate. The unexpected narratives and themes were carefully noted and further analysed manually. Analytical matrices were manually created of key topics and themes from the interviews and journal data, and these were cross-referenced across the participant groups to stimulate and create further analysis and allow complementary examination of the summarised data. Automated NVIVO tools were brought in to assist the manual analysis where appropriate, for instance: text searching, coding and coding comparison, matrix coding and word frequency queries and, less successfully, comparison diagrams and hierarchy charts.

Validation and Presentation of Findings

Various techniques were sought to strengthen the validity of this lone-researcher data collection and analytical approach, including triangulation of the data sources (across the expert levels); the iterative, abductive analysis approach to analysis using well-respected theoretical frameworks; and pro-active and stimulating discussion of methods and approaches, analytical matrices and key findings with experts (e.g. supervisors and other academics). As mentioned above, memo writing during the interviews and analysis assisted in the analysis and contributed to the interpretive stage by providing reflective frameworks for moving this forward. The process of writing thesis chapter drafts, presenting and defending at annual higher degree review panels, conference presentations and papers played a major part in the interpretation and progression of findings to the final version, with discussion of the findings with supervisors, colleagues and in more public forums supporting this process.

3.2.5 Ethics

The nature of the research required ethics approval at the site of the data collection. UNSW HREA ethics approval was initially obtained in 2011 (HREA 2011-7-25) when this research began as a Master of Philosophy (Education) degree (see letter of approval, Appendix 3.6). Ethics approval was obtained in July 2014 from UNSW HREC (the highest-level committee at the university) for 5 years (HREC14091) when research began at a part-time doctoral level (see letter of approval, Appendix 3.7). Modification of this approval was sought and obtained in April 2015, for change of lead investigator from my previous to a new supervisor following my original supervisor's move to the UK. As a result of several changes of theoretical direction and consequent changes in methodology, choice of interview participants and theoretical approach, a modification application was made and approved by HREC in February 2016 (Appendix 3.8). During this research, attention was paid to the ethical questions raised by Brinkmann and Kvale (2014, p.119), as further outlined below.

Benefits and Harms

Care was taken to examine the likely beneficial and harmful consequences of the study, both in general and for the participants. As a cautious researcher, I considered it necessary to outline to the study participants that there might be both possible beneficial and harmful outcomes of taking part in the study. This was achieved using the invitation letters, the consent forms and during verbal consent. It is possible that the learning outcomes of participating students could be either enhanced or impaired through the study's process of reflective recording and interviewing around troublesome concepts. Fortunately, as anticipated it appears that the balance tended to be positive. I was pleased that all the cases who continued to the end of the study expressed an appreciation of the process in terms of learning about threshold concepts and their own critical and conceptual learning, and in terms of learning about how qualitative research study is carried out. Furthermore, it is anticipated that the UNSW medical students would benefit generally as the teaching outputs expected for improving learning are developed in the near future.

It is an important element of research that the findings are disseminated for others to review and utilise for further research or teaching practice as relevant. Following submission of the thesis for examination, it is planned to disseminate the methodology and the study's findings via peer-reviewed publication and presentations at local, national and international education forums. Two conference papers have been presented at the 6th International Biennial Threshold Concepts Conference, in Halifax, Nova Scotia, June 2016, a chapter derived from this has been accepted for publication in the edited book *Threshold Concepts on the Edge*, and a conference paper will be presented at the Australia & New Zealand Health Professional Education conference in July 2019.

Consent

As usual for a study of this type, individual, informed consent of all the participating subjects was obtained using the UNSW HREC written consent guidelines using a hard copy of the Participation Information Statement and Consent Form (PISC) with specific versions developed for each participant group (see Appendix 3.9). Importantly, clear information on the study aims and methods was provided in advance in this written consent, with a verbal check before each interview that the participant was clear about the nature of each session and their rights regarding revocation and privacy of data. Any uncertainty about the purpose or direction of the interview was addressed prior to the interview commencing, and this was repeated at the end to clarify if the participant agreed for all the data collected to be used. In terms of the case study journal data, participants decided what they sent to me when they received my fortnightly update request. No participant requested withdrawal of their data from the study.

Confidentiality

The privacy and data confidentiality of participants was protected by limiting the number of people with access to raw data to the transcription service and myself. Participants of the case series study were not introduced to the other cases. The raw data files were stored on the network drive on a restricted UNSW Medicine server. Data being analysed in the NVIVO software on my work computer was de-identified using case numbers instead of participants' real identities. The processed, de-identified data was only shared with research colleagues (PhD supervisors) and back to participants in controlled situations (e.g. further interviews). For future publications, pseudonyms will be chosen, and it is intended that the university of origin will not be directly identified. Overall, it is considered unlikely that publication of the research findings could have any specific effect on the study participants. The findings will be directly fed back to participants via an announcement/email through the Moodle courses for all medical students currently in the medical program and directly to the expert participants.

Delimitation

This study aimed to examine the teaching and learning of threshold concepts in the QMP element of the undergraduate medical program at UNSW and the critical thinking skills associated with troublesome conceptual learning points. Due to the closeness between practice and research I expected that the data would touch on learning and teaching in other disciplines and curricula and this was analysed where it was helpful to answering the research questions. However, as these topics were outside my area of expertise, I committed to avoid analysing these topic areas too deeply and returned to the aims of the three research questions in order to maintain the project's scope.

3.3 STRENGTHS AND LIMITATIONS

3.3.1 The Researcher-Participant Relationship

As discussed earlier, my joint roles as the students' teacher and sole active researcher in the study was beneficial and also a hindrance to the research. Knowing the curriculum intimately was useful, but being the lecturer made the research relationship with students initially awkward in some cases. During the interviews, students and experts appeared to trust the research environment being created and appeared non-anxious. However, there may have been unidentified issues regarding the interviews as I am the students' lecturer. Also, as a colleague and/or friend of the experts, this could have affected the dynamics of those interviews, although this was not obvious at the time or during closer analysis. To reassure the students, I reminded them that I would not be directly marking any participant's work (e.g. exam papers) and I would be marking assignments with the benefit of the anonymous marking system. This minimised the risk of sub-conscious or conscious interference in the students' progression in the course or program assessments. Certainly, a good rapport was developed with all of the interviewees; they were not inhibited in telling me about their learning experiences.

On the positive side, social-cultural constructivist methodological research approach thrives on social interactions. Hence, the use of in-depth interviews and subjectivity and reflexivity invoked by my social constructivist-pragmatist abductive analysis method was fitting and assisted in the process of analysis and in developing the interpretations presented.

3.3.2 Evaluation of the Study

Specific criteria for evaluation of constructivist research by Cleland and Durning (2015, pp. 61–64) on *trustworthiness* and *authenticity* were used as the overall theory and design was deemed to be socio-cultural constructivist. For trustworthiness, credibility, transferability, dependability and confirmability were assessed.

Credibility

The credibility of the research relates to accepted practice and endorsement of the interpretation by the participants and peer review. In part, this was achieved as a triangulation process was used as recommended and the abductive analysis process meant that the interpretations were fed back to case study participants. There were two possible important issues regarding the conduct of the research in terms of the design. The first issue was about the TCF. The TCF was chosen as it has been used before to examine discipline threshold concepts in a similar environment, although this was for non-medical professions: nursing staff (Martindale, 2015); dentistry students (Kinchin et al., 2011); and health sciences undergraduate students (Blakey, Harland, & Kieser, 2011). These studies did not examine the actual nature of the conceptual learning process in detail, so assumptions about applying the framework could not be assumed to work as well in practice as in theory. The second issue was regarding the self-reporting process for me (the researcher) and for participants in the study. It is important to acknowledge that self-recording of one's thinking processes is inherently difficult, even if done immediately following an event. Various unmeasurable issues with memory and post-event reflection must be presumed to have altered the self-made recordings of thinking or inner dialogue (Fernyhough, 2016). Therefore, this was acknowledged as a possible bias factor in data collection and during analysis and interpretation stages. In addition, there is a possibility that participants altered their reflective recordings to suit what they believed were my expectations (subject bias). This was kept in mind also during the analysis but considered of minor importance and tolerable within the analysis and interpretation.

Transferability

The transferability of the data is a key criterion regarding validity in research. This was evaluated carefully, and some issues identified. My study investigated only medical program students and staff in the medical faculty of UNSW, so in theory, this might restrict the generalisation of my findings to these disciplinary approaches and to teaching practices within our faculty. Furthermore, this research emphasises the individual experience to the detriment of learning more about the curriculum and the wider context of critical thinking for student learning. As the concepts in my discipline are used across the health professions, I suggest that the findings should apply to medical and healthcare education of evidence-based practice at any level. Interestingly, Tavory and Timmermans (2014, pp. 126–128) consider that the processes of generalisation and theorisation from the individual's experience can inhibit the ability for research to "get close to people's lives" and argue that the extension from research to generalised theorisation may not always be the best path. This was kept in mind during the analysis and writing up process.

Dependability and Confirmability

Dependability and confirmability of the research depends on whether the research is replicable, auditable and if the researcher has been clear about their relationship to the research. The ethics application and participant documentation, personal research memos, NVIVO analysis files and the final written thesis all provide a clear record trail of my research process. However, the contextual element of the research is harder to distinguish. Brinkmann and Kvale's (2014) clear and practical criteria on quality in interviews were applied, and this approach worked to maintain the independence and validity of the process and the study findings. As to independence and impartiality of the study research and data collection, there was no research sponsor and the only funding received was in the form of UNSW grants for master's degree support and doctoral travel support. My supervisors were

UNSW academics, but were not members of the medicine faculty, allowing distance from the discipline and faculty educational politics. In this way, external and internal influences on the study were minimised. My personal involvement in the data collection and analysis could be seen as a limitation, but in fact is welcomed an advantage for the abductive approach. My medical training and deep involvement in the curriculum development and teaching of the UNSW medical program since 2004 was a positive component of the research, especially the analysis. However, I acknowledge the limitation of being a PhD student 'lone' researcher might have overly focused the analysis on my understanding of the curriculum and my personal teaching practice.

It is vital in a qualitative research approach for the researcher to recognise their subjective role in this data collection and analytical process, as "the researcher is the instrument for analysis" (Starks & Trinidad, 2007, p. 1376). Despite this effect, rigor and validity can be maintained if the research is monitored, documented, evaluated as it progresses, with the researchers' different approaches sometimes acting as an added strength (Starks & Trinidad, 2007). Indeed, the abductive analytical approach taken for this research, requires that researcher to be immersed within the data, actively experiencing it in order to gain the fullest interpretation. S. Timmermans and Tavory (2012, p. 176) emphasise that the researcher must re-experience, revisit, rethink the data with the purpose of an analytic saturation, by perceiving the data from different "theoretical vantage points" and from time points. Hence, in this thesis, the research assumes that my own subjectivity, including my "values, priorities, positions and actions" as a medical academic teacher of these students, are inherent within the analysis and interpretation of the data (Charmaz, 2014, p. 236). Being aware of this issue, I actively sought to be creative and open in my interpretations, with an emphasis on the alternate casing process of the analysis, which helps consider and include other viewpoints into the interpretation. Self-reflection processes (memo-writing and active contemplation of my role), were used to monitor and record my impact on the research and, especially, the analysis. The benefit of using my experience and expertise as part of the analytical process has outweighed its limitations, but this is hard to measure objectively.

Authenticity

The authenticity criterion brings together several important internal validity factors regarding how the study was conducted and it also queries whether the findings educate and/or have a useful impact. In terms of the conduct of research, this study was careful to examine the relevant methodological theory and research practice and followed the recommended TCF/ITCK study design with triangulation of participant viewpoints and types of data. It also used respondent involvement and feedback during the recommended abductive analysis process. Additionally, the thesis provides careful description of the study process, the analysis and the interpretation in order to assist the reader in seeing how conclusions were drawn.

A controversial topic regarding qualitative research is the need for a saturation level in terms of the data analysis. This is a term originated a long time ago in the original grounded theory approach (Glaser & Strauss, 1967), and remains the gold standard approach within qualitative research, including in medical education: as the point "at which no further new observations or insights are made" (Sullivan & Sargeant, 2011, p. 452) or "when the complete range of constructs that make up the theory is fully represented by the data" (Starks & Trinidad, 2007, p. 1375). The need for saturation, with regards to outputs as theories or data themes, is a debated point. As O'Reilly and Parker (2013) argue, there are certain methods where saturation and associated adequacy of sampling may be irrelevant and even detrimental to the research purpose and approach, for example, in conversation analysis. On the contrary, the accurate determination of the sample size necessary to reach saturation prior to a study commencing, is accepted as mostly unnecessary, unless there is a shortfall of saturation, when further data should be sought if possible (Sullivan & Sargeant, 2011). For this research, saturation was sought as far as possible in terms of the intended output's theory constructs and answering the three specific research questions.

In terms of the number of case series participants, a sample size calculation was not considered appropriate approach to take regarding data collection, due to the qualitative, exploratory nature of the research and did not aim to generalise directly from the cases (Evers & Wu, 2006). Rather, it was deemed more important to have an adequate quality and broad expertise within the case study recruitment to provide a "range of experiences" (O'Reilly & Parker, 2013), that would assist in specifically answering the research questions (Evers & Wu, 2006). Fortunately, no further data collection deemed necessary after the final case interviews were analysed. There is a total of 19 interviews (over 23 hours of audio recording, of which more than 16 audio hours was for the case series) and 27 separate reflective journal submissions consisting of over 50 dated entry items. These data provided rich material allowing deep analysis and interpretation, providing adequate data information for a successful outcome to the research aims.

Finally, the impact of this study on my teaching practice and students, and wider, is yet to be measured, but I have implemented changes within my curriculum initiated by my research, and I hope that others will use my findings in their research or teaching. As an experienced educator, I could not fail to take on the role of the learner as part of the process. Personal insight as a researcher developed through this process and was incorporated into my practice as a teacher-researcher. This added to the quality and depth of the final output, and development of the learning tools for my teaching practice. Care was taken during the analysis to define involvement in the data analysis, and any observed subjectivity was noted. In order to receive critical feedback and scrutiny, key interpretations were discussed with supervisors and through presentations. Further scrutiny of the personal journey is presented as a Coda to this thesis.

THE APPROACH IN ACTION

This chapter has justified the methodology of this research design, introduced and detailed the qualitative interview and case series study used for this thesis. It has shown how an abductive analysis approach, based on Peirce's abduction theory and modelled on a constructivist grounded theory, was utitlised to enable a close analysis of the participants' learning experiences in the liminal space. Explanation has been given regarding how the study design and research methods and techniques were chosen and carried out to maximise the validity and rigor, evaluated as trustworthiness and authenticity, of the study and its findings. In the following three chapters I discuss the investigation using the Vygotskian-based theoretical framework of conceptual elements in evidence-based practice and medical biostatistics and explore how participants overcame conceptual difficulties to gain conceptual, transformative understanding. Further, I interpret how language and critical thinking skills aided this process. A final chapter makes recommendations for new research approaches and new procedures for instructive support for the learning threshold concepts and more specifically for the development of critical thinking and practice in medical education.

CHAPTER 4:
FIRST INTERSECTION – CONCEPTUAL LEARNING AS A SYSTEM

"Concepts do not lie in the child's mind like peas in a bag, without any bonds between them. If that were the case, no intellectual operation requiring coordination of thoughts would be possible, nor would any general perception of the world. Not even separate concepts as such could exist; their very nature presupposes a system."

(Vygotsky, 2012, p. 209)

This chapter is the first of three analysis chapters that report and discuss the findings of the analysis. Here, I address the first thesis research question: identification of the transformational conceptual development domains in my discipline of Quality of Medical Practice for students at UNSW. An abductive analysis method used a Vygotskian and TCF theoretical approach in revisiting, defamiliarising and casing the data of expert, focus group and case series participants to reveal conceptual themes and develop further theory. Classifications of transformative concepts and other conceptual forms were derived from the data using the research framework allowing further investigation of associations, direct connections and underlying characteristics of the conceptual learning. Key disciplinary concept areas and levels for evidence-based practice and medical biostatistics were identified and consolidated and are presented and discussed.

4.1 EXPLORING CONCEPTUAL LEARNING

As discussed in Chapter 2, research on the conceptual learning process and TCF have stimulated more questions than they have answered on core topics such as how conceptualisation occurs in the mind of the learner, how conceptual knowledge is handled by the learner, and how and why the process of conceptualisation can stimulate a shift in the individual's ontology. These are acknowledged to be very difficult elements to examine and understand, and consequently have remained less well understood (Land et al., 2014), but, at the same time, are acknowledged to be vital for developing improved pedagogy/andragogy to support student conceptual learning (Baillie et al., 2013, p. 244).

4.1.1 Models of Conceptual Learning

As shown in Chapter Two, the research on thinking, learning and being by Säljö, Entwistle, Perkins and Barnett, provide a sound basis from which to examine the learning process and the critical thinking that takes place in the learning of key disciplinary concepts on the road to expertise. Their theories resonate and complement each other and align well with Vygotskian thinking and the threshold concept framework. Other models and frameworks used include the following: 1) Rountree, Robins and Rountree's model of K-S-M integrated with the TCF (2013, p. 279); 2) Tucker Model of Search Expertise (2012, p. 253); 3) Dreyfus & Dreyfus 5-level expertise model (2005, p. 782); 4) Krathwohl's revised Blooms Taxonomy (2002).

As introduced in Chapter Two, Rountree, Robins and Rountree's model (2013, p. 279) provides useful dynamic conceptual elements, strategies and "mental models," so it was applied to identify if these were present within the data. The Tucker Model of Search Expertise (2012, p. 253) was employed to consider the information literacy concepts and to explore the data for her idea of "concept fusion." As discussed in Chapter Three, the Dreyfus & Dreyfus 5-level expertise model (2005, p. 782) was chosen to examine expertise and practice more specifically. The revised Bloom's taxonomy (Krathwohl, 2002) was included as it is widely acknowledged as a useful framework for the curricular design of student learning outcomes and assessment. During the analysis it was used as an extra layer for examination of the knowledge-cognitive intersections within the more complex conceptual areas. My original network model (Quinnell & Thompson, 2010) of evidence-based practice (EBP) and biostatistics threshold concepts was used in the interviews, so was included as a reference point in the analysis. Together, these models, taxonomies and frameworks were employed as an analytical frame.

These models and frameworks worked well together during the analysis to identify the actual threshold learning moments and clarify other associated conceptual forms within the students' learning. The conceptual categorisations and their connectedness emerged quickly and spontaneously around this first theoretical intersection of conceptual learning as a system, with further analysis confirming the existence of personalised conceptual systems. A central premise in this analysis was that conceptual knowledge interacts with student perceptions in deep learning for both epistemological and ontological transformational changes to occur and for expertise in disciplinary knowledge and mastery to be gained.

4.1.2 Focus on the Threshold Concept Framework

At the beginning of my doctoral research in 2011, the TCF research was gaining popularity as it excelled in identifying those threshold concepts where students got stuck and disengaged. However, it was somewhat limited in its understanding of the transformational conceptual learning it was identifying. The prevailing categorisation was based on the classic threshold concept, which privileged the troublesome, integrative and transformative characteristics (Meyer & Land, 2003). It was posited that there were troublesome concepts and/or skills that were not necessarily transformational but, nevertheless, were important for learning and gaining that transformative leap (Baillie et al., 2013). For example, early research identified conceptual forms that primarily enabled conceptual learning ("modelling concepts") (Davies & Mangan, 2005, p. 6), and more recently the idea of "threshold skills" has been suggested (Thomas et al., 2017, p. 335). In addition, the notion of practice as a threshold or conceptual learning characteristic has since gained considerable traction (Haenen, Schrijnemakers, & Stufkens, 2003; Martindale, 2015; Thomas et al., 2017). Furthermore, the ideas of threshold skills and threshold practice correspond well with another adapted framework from the TCF, called the "Threshold Capability Integrated Theoretical Framework" (TCITF) as proposed by Baillie, Bowden and Meyer (2013, p. 228). This framework presents a strong argument for conceptual learning as a complex web of threshold concepts, influenced by epistemes and with the goal of "knowledge capability" (Baillie et al., 2013, p. 231). Additionally, "threshold capabilities" could be considered similar to threshold skills as they allow learners to appreciate threshold concepts properly within a professional capacity (Baillie et al., 2013, p. 236); essentially, the threshold skills put threshold concept knowledge into practice for the knowledge capability.

Despite this plethora of research suggesting these new conceptual forms, it is less clear from the research how these conceptual forms interact with each other or whether they are discipline, subject or context specific in their purpose. Some research posits that some of the not-quite threshold concepts might be "transliminal" concepts that, although they aren't transformative in themselves, can act as a "lure" to entice students into the liminal space (Sorva, 2010, p. 21). Apparently, these transliminal concepts only become truly clear to the student once integrated with the related transformative threshold concept. Additionally, Sorva and others working along similar lines, have embraced the concept of *fundamental ideas* (FIs), originally developed by Schwill (1994) from earlier work by

Bruner (1960). They consider these ideas to be "broad, general ideas that link many topics and involve long-term development" (Sorva, 2010, p. 25). These disciplinary-centred ideas are not considered transformational or bounded by a discipline but, rather, they act as topic frameworks that the learner builds on in their long journey to disciplinary expertise. Consequently, these fundamental ideas can be broad (or "master") if they run across whole discipline topic areas (Rountree et al., 2013, pp. 276–277). Researchers, mostly from information technology, computer sciences and programming education areas consider both transliminal concepts and fundamental ideas to be necessary alongside threshold concepts for disciplinary learning to occur. This resonated with my understanding of my own disciplinary learning and teaching experiences. I have noticed similar big ideas within EBP and medical biostatistics and epidemiology that are not transformational but are useful in directing and structuring the student approach to learning, for example probability in statistics, clinical measurement, and study design.

Finally, the other useful major research idea from TCF conceptual learning is centred on the identification of networks or webs of threshold concepts that are thought to assist students in gaining mastery of the disciplinary topic (e.g. Davies & Mangan, 2007, 2010). Kinchin, Cabot and Hay (2008, p. 316) draw together research to explain how networks or webs of threshold concepts appear to be creating "chains of practice" and "networks of understanding." It is not clear how these disciplinary learning conceptual pathways are transformed into characteristic ways of thinking and practising (WTP) for disciplinary expertise as first described by Meyer and Land (2003). However, it is clear that the WTP define the disciplinary approach to learning and the handling of knowledge within a subject matter. According to McCune and Hounsell (2005) experts and students studying a discipline may use these prevailing WTP to come to "terms with particular understandings, forms of discourse, values or away or acting which are regarded as central to graduate-level mastery of a discipline or subject area" (p. 257). Hence, these WTP could be regarded as the guiding disciplinary discourse map or main outline for disciplinary learning.

At the same time, relevant Vygotskian theories are useful to examine concepts and conceptual networks in other ways. As explained in Chapters Two and Three, Spontaneous concepts are fundamental developmental blocks of early development. Vygotsky's (2012) view was that these concepts are not learned through introspective play as Piaget reasoned, but through socialisation and "everyday living" (p. 164). To learn more complex academic concepts, Vygotsky described that on reaching school-age the child is introduced to this learning and guided by instruction; his examples were invariably located at school and with instruction from more knowledgeable peer or teacher. Indeed, Vygotsky (2012) was specific that these interactions stimulate the development of academic concepts in a staged process, creating a conceptual system from which the learner can grow "scientific reasoning, which in its turn favourably influences development of spontaneous thinking" (p. 157). At the time, this was a new theory that suggested previously socially learned, everyday, spontaneous concept(s) and other academic concepts can create a new, advanced understanding of corresponding higher level conceptual understandings that then concrete and systematise: "…mastering a higher level in the realm of scientific concepts also raises the level of spontaneous concepts" (Vygotsky, 2012, p. 203). In summary, the zone of proximal development (ZPD) is where this developmental process takes place and the systematisation of concepts originates. The theories surrounding these key ideas and conceptual learning approaches were kept at the core of this analytical theoretical framework during the abductive analysis for identifying conceptual learning in my discipline.

4.1.3 Threshold Definitions

The definition of key features of transformational concepts were taken from the original characteristics defined by Meyer and Land (2005). A *threshold concept* is transformative, and troublesome in terms of the content, and/or counterintuitive and/or with difficult or troublesome language; discipline-bounded; integrative; irreversible; and often part of a network. Importantly, I included the later defined characteristic of reconstitution as the ontological change as this is vital to the full threshold concept status (Land et al., 2010). Associated with this criterion is the discursive aspect (Meyer & Land, 2005). *Troublesome concepts* were defined as when the participant experienced any of the following: a significant degree of conceptual challenge or difficulty in learning a concept; counter-intuitive or alien knowledge; substantial emotional struggle; and/or suspension of belief for learning (Meyer & Land, 2005).

4.2 IDENTIFICATION OF CONCEPTUAL ELEMENTS

The identification process was a fluid abductive analysis, with frequent revisiting, defamiliarising and alternative casing of ideas and thoughts, which continued across the year of data collection and during the two years following. In the alternative casing mode, further models from the literature were overlain on the TCF framework to refine the conceptual status of the troublesome learning areas more clearly. Despite the additional influence of these other models, the TCF approach dominated the early abduction for identifying the troublesome and transformative conceptual learning, with the themes growing up around this (Appendix 4.1). The other theories and models were used to clarify the threshold concepts and concept themes that emerged from the data. Underlying this was the Vygotskian perspective, providing theory around conceptual forms, networks and learning.

4.2.1 Clarifying Conceptual Forms

This analysis was difficult; I struggled to categorise concepts that were not classic troublesome, transformative, integrative concepts. The theory and models were vital to the whole analysis, so the processes, features and findings are interwoven in the findings to illustrate where theory was involved in the abduction and where this created new theory and ideas. From this application of theory to the data, alternatively cased across expert and student participants and the research literature, I developed an expanded framework of conceptual learning of the most common conceptual forms (detailed below as a final categorisation framework in Table 4.1). These categories were derived during the data analysis using the combined theories mentioned above and refined with each wave of abductive analysis of the data. Each concept mentioned was examined to identify whether these met the threshold concept characteristics, and especially if they were deemed transformational in terms of knowledge or belief by the participants (experts and student cases). Some key concepts were not deemed troublesome by the participants but were thought to be complex or complicated instead. Further iterative analysis was then carried out to identify their key characteristics. Where the data and theory provided evidence, I conjectured how these conceptual forms interrelate. A list of conceptual forms is presented in Table 4.1 to act as a classification to assist the reader in understanding how the threshold and related concepts and ideas were identified for my disciplinary area.

Table 4.1 Conceptual elements of the conceptual learning framework by expertise level

Conceptual Form	Expertise Level	Explanation
Simple idea	Basic	More than a simple thought but less substantial than a concept.
Simple concept	Basic	Straightforward and easy to learn for most students. Could be tacit knowledge. Synonymous with the Vygotskian non-spontaneous, everyday concept.
Fundamental idea (FI)	Basic-mid level	A broad, general idea often based on everyday understandings. It is applied in a disciplinary manner to conceptual learning. Easily meaningful to people and also can be expressed in everyday language. Not usually troublesome for learners.
Complex, non-transformative concept	Complex, mid-level	Complex concept and often troublesome to learn but not transformative.
Transliminal concept	Complex, mid-high level	Non-transformative concept but can act to entice the learner into the liminal space and engage her there until transformative learning occurs. Could be an essential and/or interesting element of the TC itself.
Master fundamental idea (MFI)	Long-term use in mid-high-level learning	A big fundamental idea, which brings together many ideas in the discipline and can extend across to other disciplines, remaining important at all levels of expertise.
Threshold capability, skills and modelling concept	Complex, mid-high-level	Complex facilitating concepts and skills. Can be troublesome, even transformational. Also, enable the transformation process of TC.
Threshold concept (TC)	Complex, mid-high level	Concept that has the key TCF characteristics of a TC: transformative and integrative of other concepts and FIs. Usually troublesome and irreversible. Results in epistemological and ontological transformative shifts. Learner gains a new way of seeing the disciplinary subject matter and context. Synonymous with the Vygotskian academic concept.
Network or web of any of the above	High level: linked relationships	A linked collection of concepts, ideas and TC. Integrative but extended horizontally across the discipline and linking up topics and concepts.
Ways of thinking and practising (WTP)	High- level: requires transformation	Assists transformation and aids disciplinary practice of conceptual learning. Could include TC, other concepts, fundamental ideas, essential skills. Learned through experiential learning, modelling by practitioners, authentic and work-integrated learning.
Overarching Threshold Practice - "Knowledge Concept"	High-level: requires transformation	Brings together multiple TC, concepts and FI within one perspective. Key disciplinary theory. Works together with the WTP to initiate a whole new way of thinking and practising the discipline.
Expert Identity, Mastery and Praxis	Highest: requires transformation, accumulation of many WTP, FIs and TC	A long-term, often life-long learning that accumulates and modifies the over-arching threshold practices and WTP, the master fundamental ideas and the ways of thinking and being into an identity as the disciplinary expert.

The next stage of analysis examined all concepts considered troublesome or transformative by triangulating the interviews experts and student cases with the reflective journal submission. If these were considered main concepts they were examined in detail (see Supplementary Tables S4.1-S4.11, Appendix 4.2). The analysis focused on concepts and domains considered essential to a medical student's journey to graduate-level expertise in Evidence-based Practice and Medical Biostatistics. A fuller analysis of how these concepts interact and link was not undertaken for two reasons: 1) identifying the conceptual elements within my curriculum was necessary for further exploration of the liminality experienced by the participants, but this was not the main focus of the research; 2) the analysis was taken as far as it could go considering the design of the study and the quantity, quality and depth of the data available for this particular aspect of the study. These same reasons indicate that there may be other conceptual forms not identified by this analysis, and hence further research is recommended that is directed specifically at delineating these conceptual forms in more detail.

4.2.2 Conceptual Learning Experiences

All participants reflected on several experiences involving difficult or troublesome concepts and all identified various critical thinking skills that were used in learning and understanding these. A surprising discovery was the sheer number of troublesome and/or threshold concepts or other concepts in EBP and medical biostatistics the participants had identified; there were 34 in total with 11 high-level concept forms and 23 low-medium level forms (Appendix 4.2). These are summarised in Table 4.2 below. Initially, some of these were categorised into different disciplinary focus areas but following reiterative viewing and alternative casing were considered by the end of the analysis to overlap or to be very similar concepts viewed from a different disciplinary focus or perspective. In addition, the participants identified troublesome concepts from across medical science and clinical disciplines that were outside of the original research discipline area. Students also mentioned troublesome concepts from previous learning experiences going back as far as primary school. First-year students found it useful to talk about these in their first interview at the beginning of their degree program, when they had little new knowledge or experiences of the medical curriculum concepts to discuss. Some of these troublesome and transformative learning experiences were considered in the analysis as they were informative regarding the process of conceptual learning.

Table 4.2 Conceptual elements identified for EBP and Medical Biostatistics

Topic	Conceptual Form	Expertise Level	Justification
EBP Clinical Practice Perspective	Over-arching TC as practice	Expert Level is WTP.	Transformational, fully integrative. A fusion of many TC, strategies/skills and models.
EBP Cycle Process	Holistic framework/ tool	Expert incorporates into WTP.	Competent student can see how these steps work together but are not quite able to use as WTP in clinical practice.
EBP Step 1: Asking	Troublesome capability, not always transformative	Key clinical skill, competency improves with real practice.	Skill-heavy conceptual domain, several difficult concepts/skills involved here.
EBP Step 2: Acquiring	An Integrated TC with WTP key to the integration	Expert when fully proficient and can transfer across disciplines as WTP.	Incorporates many TC, concepts and fundamental ideas with key skills. A complex domain that integrates many simple, complex, multiple troublesome concepts. Some transformative, overall is transformative at level of WTP. information literacy is key element.
Information Literacy:	A WTP domain	A WTP for those who become experts in this practice.	Complex network of concepts and skills integrated as WTP in expert. Transformative, troublesome and integrative.
Basic database search	Integrative TC.	Transformative at competency and expert levels.	Troublesome conceptually and transformative when expertise level increases. Surprisingly, senior still students still struggle with this,
Choosing a Boolean term and logic	TC for some, simple concept for others.	Competency takes search ability to another level of ability.	Essential part of the basic database search above. Appears to be a simple concept, but can be counterintuitive and confusing, and transformative.
Evaluation of sources and search hits	Multiple complex concepts with skills.	Competency helps toward WTP in information literacy and the EBP Step 2.	These are probably separate complex concepts and TC but require very similar skills. Similar but different skills required for the critical appraisal skill.
EBP Step 3: Appraising	Over-arching threshold practice	Expert Level is WTP.	Troublesome but transformative and irreversible. WTP integrates multiple concepts through understanding & application. Also, essential element of overarching research threshold.
Understanding Bias & Study Design	A major, complex, integrated threshold concept.	Transformative at competency and expert levels. Expert integrates these for EBP WTP.	Understanding of many individual biases is required for full transformation and to carry out a full critical appraisal. These are troublesome-complex concepts and could be TC for some students. Links to many others, e.g. internal and external validity.
EBP Step 4: Applying	Over-arching threshold practice	Experts can take this further to an over-arching clinical practice domain/WTP.	An integrated applied complex of other concepts, including TC such as clinical significance (external validity), clinical reasoning and clinical significance.
Clinical significance, clinical reasoning, judgement, clinical perspective	Probably TC in their own right, integrated for clinical practice.	Transformative at competency and expert levels. Expert integrates these for EBP WTP.	Contains TC knowledge but there is transformation in the *practice* of these TC. All these elements contain some degree of critical thinking/ perspective/ approach.
Patient risk levels, assessment & estimation	A network or web of several variably troublesome concepts.		Allied closely to the EBP overarching practice TC. This could be one of the conceptual transformations that assists development of the overall EBP WTP.
Diagnosis & screening principles	Threshold concept elements.		TCs present in the underlying principles and how to apply the evaluations to patient. Vital concepts for patient care.
EBP Step 5: Assessing	A TC (for some)	Threshold to expertise is practice. Some achieve this earlier, some only later in professional practice.	An essential element of reflective clinical practice which is an accepted WTP and key competency for professional practitioners in many disciplines and specialties.

Topic	Conceptual Form	Expertise Level	Justification
Biostatistics: Sampling Perspective	Overarching threshold as WTP	Transformative the competency and fully integrative for the expert.	Sampling is universally accepted as a transformative and troublesome concept. Most research agrees that it requires understanding of all underlying concepts/principles for full understanding of sampling.
Data & distributions	Central concept.	Expert integrates this into full Sampling Perspective WTP.	Central concept in statistics and research. TC characteristics but probably more 'everyday' knowledge which is reworked.
Central limit theorem	A threshold concept.		Central to the process of inferential statistics based on samples. Overwhelmingly seen as a particularly dense threshold concept.
Summary statistics	Several mixed conceptual elements.		Understanding of several conceptual elements and skills required (e.g. central tendency). Not usually transformational but can be troublesome for some students.
Degrees of freedom	A threshold concept.		A PhD level concept but is a basic statistical principle. A classic TC; it has all the TC characteristics.
Biostatistics: Understanding Significance Perspective	Overarching threshold as WTP	Is the WTP level. Provides the whole perspective.	An overarching threshold concept - transformative, fully integrative.
Hypothesis testing	A threshold concept.	All of these contribute to the Significance Perspective WTP. Competency achieved when understand and expertise level gained at WTP.	Central to the use of sampling in statistical testing. Troublesome conceptually and in language, integrative.
Significance	A threshold concept for some.		Involves understanding sampling and the interpretation of p values, which appears to muddle everyone initially. Troublesome, transformative and irreversible.
Confidence intervals	A threshold concept for some.		As part of the expression of statistical significance but complex in its own right.
Type 1 and 2 errors	Complex concept.		Troublesome, difficult language. Assists in transformation for significance TC.
Clinical significance	A major threshold concept.		Step 4 of EBP: effect size and statistical significance applied in practice alongside clinician and patient factors. Aligns with internal and external validity.
Effect size	Complex concept.		The results of hypothesis testing. Confusing and often forgotten in favour of the significance measure but key complex concept in clinical significance.
Research Perspective	Overarching threshold as WTP	The key transformational step to expert practitioner is actually practising research. Transformational.	Understanding all the related threshold and troublesome concepts, with the ability to judge validity creates an integrative, transformed way of seeing research. WTP required to draw all this together cohesively.
Data and sampling	Over-arching WTP.	Competency in research is achieved when all these conceptual elements are understood. Expertise in WTP is achieved when integrated fully in practice. Transformational at both levels.	For research, need to understand sampling concept. General agreement regarding sampling as an overarching transformative threshold concept.
Study designs	A complex, integrated TC.		How research is carried out in trials and experiments. Quality of the evidence depends upon this.
Understanding bias	Complex integrated threshold concept.		Troublesome concepts making up a way of thinking about research study design, especially 'confounding', but also 'loss to follow up' and 'intention to treat'.
Validity, internal	Complex concept or TC for some.		Students find this concept troublesome. Involves examining biases, study design, data, sampling and statistical analysis and interpretation. Appears to draw these all together with a research perspective.
Validity, external: generalisability	Complex concept or TC for some.		Students find this concept troublesome. Overlaps with EBP-Clinical Practice overarching concept and several concepts within it e.g. clinical significance. As with internal validity, this concept draws together several others in practice.

Awareness of difficult concepts and key transformation points in learning was universal amongst all participants, from expert 'down' to the comparatively naïve first-year student. Expert 3 summed this up well:

> Yeah, I suppose I've always been aware of threshold concepts, I don't think I've actually known them as threshold concepts until I started talking to you, I've always been aware of the fact that .. there is a eureka moment where you suddenly think, oh, that makes sense. (Expert 3, Paired Interview)

Despite having planned teaching activities and curricular content carefully around these difficult points in learning, the experts agreed that students still get stuck: "I think in stats though there are some key things that a lot of them get stuck on anyway, so this is one of the things we visit in our short courses." (Expert 2, Paired interview). This suggests that experts were not aware of the TCF but were aware of the main troublesome concepts in their teaching curriculum. Furthermore, they were targeting these with specific teaching approaches already but still found that students 'didn't get it', even with more assistance. Indeed, a recurrent theme in the experts' conversations and data from the more mature students, was the emphasis that statistics as a way of thinking was inherently difficult to understand, troublesome and transformational:

> …it is all about the concepts of statistics that it is hard for them to understand … I think it's a clear transformation to understand that statistics is … in essence the quantification of the probability of something being true … (Expert 4, Paired interview)

The EBP concepts were not considered any easier, with the concepts of bias and study design being identified as especially troublesome areas of learning, and, at the same time, absolutely vital for competent clinical practice. It was recognised by many experts and the more mature students, that learners needed to adopt ways of thinking and practising (WTP), especially of threshold concepts, to achieve expertise as a practitioner within a discipline. These important findings are discussed in detail later.

Lastly, analysis of conversations with the experts revealed some conceptual areas that did not fit into traditional definitions of concepts, transformational concepts or practice-based skills. Some of these were classified as basic ideas, simple, easy concepts that were considered to be tacit and basic knowledge (discussed further below). Also, experts mentioned broader, fundamental ideas that help to define the discipline and practice but aren't necessarily bounded by the discipline (Schwill, 1994). For example: the idea of *disease* in itself, conversely the idea of *health and well-being*, and the notion and principles of *professionalism*. In looking at these topics, these are ideas that are universally understood across the healthcare professions. They appear to help to structure the learner's way of thinking and practising, and so have considerable influence on the shape of teaching and learning. Fundamental ideas were seen by experts as being inherent in the curriculum and influential in the way we learn conceptually within and across disciplines (see Table 4.1 above). Interestingly, fundamental ideas were not as clearly identified by students. Where relevant, these are included in the analysis presented below and summary analysis tables (Appendix 4.2).

4.2.3 Troublesome Concepts in EBP and Clinical Practice

From the data, I identified clinically relevant EBP and clinical practice concepts that were mostly troublesome, often transformational and integrative, usually irreversible, but not necessarily deemed bounded, discursive or reconstitutive by the participants. Of interest was the finding that these concept areas closely matched the EBP cycle (Straus et al., 2011) and the current core competencies of EBP (Albarqouni et al., 2018). For the students, this could be construed to be due to the reliance of my curricular design (and hence their learning) on these sources, but this was less of an influence for the experts, as the four non-clinicians would not have been exposed to these. The analysis is summarised here with full analysis details in Appendix 4.2. The major themes that developed from the analysis fitted well with the way we teach EBP (see Figure 4.1 below):

EBP considered as a holistic cycle of 5 steps
EBP Step 1: Asking clinical questions
EBP Step 2: Information literacy and related sub-concepts
EBP Step 3: Critical appraisal
- Understanding bias and study design
- Understanding basic medical biostatistics *(considered separately)*

EBP Step 4: Clinical application step of EBP
- Clinical decision-making, reasoning and judgement
- Diagnosis and screening principles
- Patient risk levels, assessment and estimation

EBP Step 5: Assessing/Evaluating

Figure 4.1 Major conceptual themes arising for EBP

EBP as a Whole Cycle

In general, evidence-based practice is taught to undergraduate students as a clinical process consisting as a cycle of five steps, as detailed in Chapter One (Figure 1.2). Expert 1 reflected that the recognition and acceptance of the EBP steps as a "habit of practice" might be a key threshold concept: "…if you just need to identify what the steps are in becoming competent in evidence-based practice, then I guess they're threshold issues" (Expert 1, Interview). He explained further that the acceptance of these steps as a way of practice is not a simple conceptual transition and requires a change of habit so that the process becomes "concrete and second-nature." Interestingly, the cycle itself was only occasionally directly reflected on by student participants, but all the students found at least one, and more commonly three or more, of the individual EBP steps to be troublesome and sometimes transformative, integrative and irreversible. The focus group students also talked about their struggle with understanding this as a whole process during their early years in the medical program. They seemed surprised that putting these apparently simple five steps together and applying them in practice could be so complex and difficult.

Experts considered this as key part of full clinical way of thinking and practising for clinicians. More competent students found that they could go through the cycle but didn't perform this automatically in their everyday practice. They acknowledged that a lack of experience in applying this way of practising in different situations and to different patients might contribute to not quite thinking and practising as a clinician would. This suggests that they are not quite at the high-level stage of this as a WTP. From this analysis, I propose that the 5-stage EBP process should be classified as a WTP. Further detail is given below regarding the individual steps and how they work together in practice, with discussion of the implications of this for student learning. See Table 4.2 above for summary details.

Step 1: Asking Clinical Questions

This first step of the EBP Cycle revolves around the formation of the clinical research question, structured as a 'PICO' question; P- Patient/Population; I – Intervention; C – Control/comparison; O - Outcome. This is usually formed by the practitioner during or just after taking the history and performing an examination of the patient. Several students mentioned that they found this task quite difficult as novice students, as it was complicated having to communicate clearly and choose key subject terms on medical topics, which they did not understand well at this stage. On the other hand, more mature students and experts were so comfortable with this practice that they did this automatically and often did not appreciate it anymore. In addition, the data showed that there is troublesome language involved here; experts and students recognised that high-level patient-doctor communication skills, as well as some decision-making skills, were required for this concept to be put into practice well. They also realised that several clinical and communication elements need to be mastered to achieve a good clinical question.

This finding equates well with the literature and the models. The recently published EBP core competencies document considers this as a core step in the cycle (Albarqouni et al., 2018). On applying the K-S-M model (Rountree et al., 2013), this further revealed that not only was basic knowledge about this EBP step needed but that certain strategies (e.g. taking a good history and remembering to focus the question to the individual's situation) were needed in forming the clinical question well. Specific mental models (e.g. personalised 'PICO' structures) are developed by the learner to assist in their learning and becoming proficient at this step of the process. Furthermore, authentic practice in the clinical environment was mentioned by both experts and students to be the most useful learning process for this to become a transformative experience. Those students who hadn't been exposed to this sort of clinical practice, felt that they hadn't experienced transformation and hence felt stuck at a more basic level of understanding and non-transformed way of practising.

There is more than one concept involved here and many skills interacting with it, so taking this into account, I considered this EBP step to be a web of troublesome concepts and skills that could be transformative (especially around the history-taking) for some students. Transformation within this step appears important in leading to the more expert and clinical holistic approach to EBP.

Step 2: EBP: Information Literacy

Information literacy is a cross-disciplinary skills-based subject actively taught within higher education and medical curricula as essential to sourcing and evaluating relevant evidence for research, writing assignments, and reports and for practical applications, such as for clinical practice. It is inherent in evidence-based practice as the second step of the EBP cycle and links directly to the adjacent EBP steps: Step 1, “Asking clinical questions” (used to clarify the search terms for literature search) and Step 3, “Appraising the evidence” (Straus et al., 2011).

From my analysis, information skills for medical students appears to be a complex network of individual concepts, principles and skills. In the literature some of these concepts and principles were described as transformative in the early days of TCF research (e.g. Blackmore, 2010). Also, several key expert librarian researchers had proposed an overarching transformational concept of information literacy (Blackmore, 2010; Townsend et al., 2011; Yorke-Barber et al., 2008). More recently, in her doctoral research on information search expertise, Tucker (2012, p. 238) found that a threshold concept she named “concept fusion” integrates three major information literacy threshold concepts. The three practice threshold concepts she identified were: information structures (databases and navigation of these); information vocabularies (the language of searching and libraries, including: being fluent in the process of choosing and employing search terms, understanding indexes and search retrieval algorithms), and the information environment (understanding the holistic model of information so that the researcher can apply information knowledge and skills effectively). In her model, these three threshold concepts are united by a further threshold concept she called “concept fusion” (Tucker et al., 2014, p. 158). She also identified certain traits and praxes that were essential in the process. These praxes were approaches, tools and strategies, and traits were related to the learner “characteristics, qualities and attitudes” such as perseverance and exploring (Tucker, 2012, pp. 247–248).

On evaluating her research, I agree with the idea of the three practice threshold concepts, although these are quite high-level concepts (probably as Tucker’s research was based on post-graduate learning). However, I am less convinced by the idea of a unifying threshold concept. From the prevailing TCF theories, it would be more consistent to categorise this as an intrinsic part of the meta-threshold of information literacy information environment concept, that is transformative and integrative in bringing together the other two threshold concepts. As she explains, the individual’s praxes and traits might facilitate or thwart this integrative, transformative process. Indeed, I wonder if the threshold concept identified as the information environment could in fact be the same as my integrated threshold concept web of this whole step; not just the viewing of the process holistically, but also in the doing of it, the mastery of the practice. This required further analysis.

Using this latest research from information science, combined with analysis of the data, and my threshold concept model (Quinnell & Thompson, 2010), I concluded that for full understanding and application (as an advanced skill), the student requires understanding of three main concepts/skills. These are: 1) evaluation of sources (i.e. choosing the best database); 2) basic database search (specifically the search terms to choose, how to structure the search strategy and using correct Boolean terms); and 3) evaluation of search hits (i.e. determining the best, most relevant evidence). All of these concepts include knowledge and skills identified as troublesome by the student participants and experts.

Novice students were quite frustrated by their lack of ability in doing even the most basic of searches to gain useful evidence for writing their research assignments. Part of the problem was that they knew that they were inexperienced and seemed overwhelmed by this. Some students were so adversely affected by their feelings that they were afraid to try out their skills and make mistakes in order to learn. A first-year describes how he felt:

> No, I don't really think I had a lot of knowledge regarding researching, particularly using medical data versus to looking at articles and books and e-Journals. So, during the first few weeks, unfortunately it was extremely frustrating for me, because I felt lost. This was the very first time I was doing it and I was completely disoriented regarding how to use the medical data, because, for instance, whenever I went on Medline, I found it extremely difficult to narrow down my search, because there is such a plethora of information out there. (Case 1, Interview 1)

This experience sounds unpleasant, with frustration and disorientation leading to ultimately feeling 'lost' when trying to find the best source to use and in focusing his search. This feeling of getting lost and confusion could contribute to the high degree of despondency noted by first- and second-year students in their early attempts at searching in class and for their early course assignments.

What was surprising was that many of the student cases recognised that searching involved critical thinking skills in terms of appraisal of the study design and bias in "order to be able to distinguish between high and low-quality evidence," (Case 1, Interview 1). He reflected later in his journal that he "spent considerable time" trying to understand the peculiarities of all the different study designs. In addition, the data showed that these medical students realised that the basic search concept and related skills are inextricably linked to the other EBP skills, as well as several of the basic biostatistical concepts. This concurs with current TCF literature (Tucker, 2012; Yorke-Barber et al., 2008). Finding and using evidence effectively has been acknowledged as a vital but annoying skill for modern-day health professional students; they see it as the "bane of student life" and miss the point of it being essential for basic clinical practice beyond their current academic study (D. Roberts & Ousey, 2011, p. 333). Fortunately, Case 1 was able to overcome his difficulties by doggedly following the basic principles laid out by his teachers, practising the searches as directed in class. When he finally understood how to do it, simultaneously he came to realise the importance of this approach for his future practice:

> *More importantly, learning to navigate my way through medical databases has been an even more significant personal breakthrough. For example, narrowing down my search to a particular type of study in peer reviewed journals, effectively using Boolean operators and various available functions aimed at narrowing down the search results, locating articles by a particular expert and learning to select the appropriate articles seems to be the first step in the world of evidence-based practice*. (Case 1, Journal)

This suggests that it is possible to overcome initial difficulties with information literacy, if an individual's determination is good and there is structured teaching that keeps challenging the student and assists them in experiential practice. As seen above, valuing is a key aspect of motivation and engagement – as a competent or expert practitioner of information literacy. This is endorsed by Martindale (2015) in her thesis on EBP in nursing, as she sets great store in the acceptance of practice being a presage to transformation. This suggests that there might be a fundamental idea and/or an integrative over-arching element associated with this learning, which acts synergistically to transform students' understanding into the way of thinking and practice.

In terms of the K-S-M model (Rountree et al., 2013), my data suggests students need to employ many different strategies and models to create a good search and evaluation. Also, this process involves the application of multiple, individual but linked, complex and troublesome concepts, and the use of skills and principles in a true experiential learning style (Kolb, 2015). This suggests that this step of EBP is an overarching threshold practice, rather than a single complex threshold concept. Indeed, students identified this whole step as transformative; they felt as if they were on the way to becoming a clinician when they practised this holistically, more so if they learned it in an authentic practice situation.

In summary, the consensus in the literature is that information literacy contains many threshold concepts and may be a threshold in itself (Yorke-Barber et al., 2008). Rodrigues and Sedo (2008, p. 3) found that it is a "threshold concept because we see information literacy as a social practice that extends beyond information gathering skills." On the other hand, Hofer, Townsend and Brunetti (2012), and Blackmore (2010) identified several separate concepts and skills required for information literacy and thought that these needed to be used coherently together but did not consider that these constituted a holistic threshold concept. Placing my findings in this context, information literacy as a whole approach appears to meet most of the threshold concept definitions. In conclusion, for the learner, information literacy as an approach appears to be a complex integrated threshold concept, a complex of basic concepts, principles and threshold concepts, which applied together become the WTP of information literacy. This is transformative, so that the learner can take a more expert approach to information searching and evaluation within her practice. Perhaps controversially, there is some evidence to suggest that this WTP is discipline-specific, unless the individual is experienced in searching across disciplines, (which could be the next level of mastery).

Step 3: Critical Appraisal

Critical appraisal is the ability to critically examine research evidence, come to a conclusion about the validity of its findings, and be able to convey this or use this appropriately as evidence. To be competent at critical appraisal, one should be critical of study design and other clinical evidence. Coincidently, this practice requires many of the critical thinking skills that this thesis was exploring, including assessment, evaluation and synthesis. Critical appraisal leads to the detection of internal validity issues, which involves the understanding of (incidentally troublesome) research concepts such as study design and bias. Also, it crucially requires the understanding of external validity or generalisability (in statistical and epidemiological terminology), or clinical significance (in EBP and clinical practice terminology).

My opinion prior to this research was that the troublesome topic area of critical appraisal was due to the difficulty of bringing several key sub-concepts together as a process, rather than it being recognised as a discrete threshold concept. However, initial data demonstrated clearly that most students and all experts experienced this EBP step holistically as troublesome and transformative. Yet, on further analysis, conflicting data suggested that it could be either a transformational threshold concept, an application of several key concepts as a network or an integrated concept, or a threshold skill. One interesting short exchange (paired interview, Expert 2 and Expert 3) illustrates this nicely. A total of eight exchanges were examined in detail. Expert 3 was adamant that critical appraisal isn't a threshold concept in itself, but, "if there is a threshold concept around critical appraisal it's what you do with it, it's not the individual things" (Expert 3, Paired interview). Their discussion continued in this vein, confirming a final, agreed opinion that critical appraisal is "centred around a whole bunch of" concepts, rather than being an "overarching" one (Expert 3, Paired interview).

In contrast, Experts 4 and 5 (both clinical teachers) thought otherwise. Through several threads of their conversation these experts were keen to discuss the major EBP threshold concepts and considered critical appraisal as a key conceptual skill (not a pure knowledge concept) that they considered to be definitely transformational and troublesome. This decision appeared to derive directly from their understanding and application of clinical research, with their opinion that knowledge of bias is the most important element to be detected and understood by practitioners, as shown by this extract:

> It's only once you've got all those basic concepts together, then you can critically appraise somebody else's work appropriately, and then you can see what they did wrong, in inverted commas – and that is largely a question of bias. (Expert 4, Paired interview)

Student data confirmed that critical appraisal provided them with some excruciatingly troublesome learning moments especially early in the medical program. The most mature student (Case 3) was best able to describe this as she was just post-transformation, feeling that she had finally gained her critical ability during her 4th year fulltime research project. With respect to using appraisal of evidence and putting this into practice (e.g. for an assignment or for a clinical situation), she felt that she no longer had "to think so much" about appraising a source now as it just "makes sense" (Case 3, Interview 1). In her second interview, she confirmed that the critical appraisal process had become automatic for her.

The literature concurs with these findings. Research into medicine curricula has shown that the critical appraisal step is considered the most difficult step of the whole

EBP cycle as “it integrates elements from epidemiology, information science and biostatistics, to critically appraise evidence” (Ilic & Maloney, 2014, p. 125). Moreover, it is considered central to the teaching of EBP and statistics (Astin, Jenkins, & Moore, 2002). Other research points to this as a difficult skill to teach and learn because effective teaching of critical appraisal needs to be clinically oriented (Greenhalgh, Howick, Maskrey, & Evidence Based Medicine Renaissance Group, 2014). Indeed, there is a curricular trend to teach medical statistics using an EBP curriculum with critical appraisal taught as one tool of many, with the primary aim of teaching statistics for medical practice (Greenhalgh et al., 2014; Straus et al., 2011). This is compared to another, older style of teaching using a more focussed critical appraisal lens (Astin et al., 2002).

Martindale (2015) examines the nursing literature on this topic and demonstrates that the literature supports critical appraisal as a threshold concept for nursing students. Troublesome and dependent on other troublesome knowledge and concepts, she concludes that this topic requires careful teaching and alignment with clinical practice and research skills for effective learning (Martindale, 2015). Looking more widely at the literature, critical appraisal is judged to be a key skill in generic academic literacy and equivalent to critical reading skills espoused for all undergraduate learners (Blackmore, 2010; Jones, 2009) and postgraduate students in higher education (Iyer-O’Sullivan, 2013; Kiley & Wisker, 2009). On applying the K-S-M model (Rountree et al., 2013) to the data and the relevant literature, this suggests that experts are able to use critical appraisal automatically, they don’t need a crib sheet or tick list, as they have models and strategies in their head that they can utilise for different study types and designs.

For this EBP step of critical appraisal, my research findings align with current evidence that this is a vital and universally troublesome concept to teach, and that it is equally difficult to learn in medicine as it is in other disciplines. From my analysis, I believe that critical appraisal should be considered a troublesome conceptual complex, involving the understanding of several concepts and practised with the correct application of multiple skills, principles and sub-concepts. Essentially this is an over-arching threshold practice; a complex network of troublesome concepts and skills that becomes automatic as the learner takes on the disciplinary way of thinking and practice, which then acts to transform her way of practising medicine.

Sub-concept of Step 3: Understanding Concepts of Bias and Study Design

As mentioned above, the understanding of research and study bias is acknowledged as a key concept in evaluation of clinical evidence and is a major conceptual area for the third step of EBP (critical appraisal). From the data, all of the experts identified this as a key EBP concept, however, Experts 4 and 5 were alone in agreeing that the understanding and detection of bias was central to the understanding of all the other EBP concepts, essentially bringing the concepts altogether:

> I think it's a transformative concept because it's impossible to understand the purpose of statistics if you don't understand bias. So, the actual transformative step is to understand the concept that all of those biases are unmeasurable, in essence … and that the concept of a perfect trial that removed all of those biases leaves you with a mathematical construct we call statistics, which measures how likely that answer is to be true. (Expert 5, Paired interview)

Essentially, this expert pair in discussion considered the link between this concept and critical understanding of evidence as fundamental; the knowledge providing the ability to evaluate (the skill). For these experts, this concept appeared integrative, bringing together several concepts into a skilled practice. They also considered it extremely troublesome, especially so in terms of language regarding the bias of confounding. They were adamant that as a practised skill, this practice of critical appraisal was rarely lost once it was gained; the learning is irreversible.

Students appeared less able to reflect on these concepts (probably due to being novices or advanced beginners) but they all identified bias as a key troublesome learning concept and some students identified certain sub-concepts, such as intention-to-treat, loss to follow-up and confounding, as especially difficult to understand. Taking intention-to-treat analysis as an example, this is a study method used to minimise a form of bias resulting from participants moving intervention group or dropping out of the study. Case 3 reflected specifically in a journal submission, that this "*suddenly MAKES SENSE*" (Case 3, Journal entry, April, emphasis in original). Early on in her clinical 5th year, she had realised that understanding the clinical context of study design and bias had finally helped her to gain an understanding of intention-to-treat. This had been taught to her in first year but had remained troublesome to her since then. Simultaneously, she found that she gained a new ability to be critical regarding the whole of a study's design; the revelation regarding the intention-to-treat issue and related study bias had enlightened her whole understanding of all bias concepts; this transformation was fully integrative. All of a sudden, she says that she found that when beginning to appraise a clinical trial "*I already have an idea in my head of the ideal study design and issues with other study designs*" (Case 3, Journal). Applying the K-S-M model (Rountree et al., 2013) to my data suggests that there are multiple inner mental models that assist with the implementation of the conceptual understanding in practice. This suggests that there is high-level conceptual fusion and practice taking place here.

In conclusion, bias, study design and validity appear to be troublesome and possibly transformative concepts that are all necessary for the practice of critical appraisal. They appear to be complex, integrated threshold concepts that link to others and are assimilated further into the critical appraisal over-arching threshold practice.

Step 4: Applicability

The fourth EBP step is the clinical application of the best available evidence. All of the experts were keen to emphasise the skills of understanding research design and principles, as well as study design and bias problems that can arise and cause external validity issues. Likewise, they mentioned the importance of bringing this conceptual knowledge into the clinical application of evidence for the patient's situation. Other expert and student data were less strongly in favour of this, preferring 'thinking like a researcher' as the overarching conceptual understanding required for this subject area. Specifically, these participants considered it necessary to understand of both types of validity – both internal (study quality, e.g. study design and biases etc.) and external validity (generalisability). For example, a clinical expert thought that understanding generalisability/external validity as part of critical appraisal for clinical significance was a threshold in itself:

> … one of the things I'm trying to achieve is a threshold understanding that a paper can … have a high level of credibility and the technical aspects of it are entirely trustworthy and likely to represent some version of the truth, but that's irrelevant outside the context of your practice. (Expert 5, Paired interview)

Students did not identify the concepts of validity as clearly but first and second years identified them as "confusing" and found it hard to "understand the difference" between them.

Overall, I concluded, as viewed through the TCF and other models, that applicability (the application of evidence in clinical practice) meets the requirements of the threshold concept characteristics. Furthermore, there are clear disciplinary differences in the language and practical application of these concepts. This seems to be an overarching threshold practice, consisting of several rather than just one threshold concept. Again, this is seen as a ‘practice’ as it has societal value when used competently within the workplace. The following sub-concepts were identified and considered key to this practice: clinical significance, clinical reasoning, judgement, clinical perspective; patient risk levels, assessment and estimation; screening and diagnosis.

Sub-concepts 1: Clinical Significance, Clinical Reasoning, Judgement and Clinical Perspective

Clinical significance is the application of statistical evidence and clinical interpretation of findings to the patient situation. This was categorised from the data and casing to the literature as troublesome and integrative and hence designated a discrete threshold concept. The clinical significance concept closely parallels the biostatistical concept of external validity and the research concept of external validity/generalisability. It is in the application of this concept where disciplinary differences occur; the WTP for the disciplines is distinctive, especially the reasons for when and why the concept is applied. Clinical reasoning, judgement and perspective, were similarly considered separate threshold concepts/skills. In the data they had slightly different conceptual bases and contexts but overlapped with each other and clinical significance.

Sub-concepts 2: Patient Risk Levels, Assessment and Estimation

Assessment and estimation of patient risk levels is a vital concept in patient assessment and treatment, combined with clinical reasoning to empower clinical practice. This involves, but is not limited to, the understanding of binomial distribution, risk and probability, and the complex process of balancing the benefit and harms of intervention for the patient. This was not identified as explicitly transformative by student cases but seen as complex and troublesome by experts and more competent students. In addition, experts and the highest-level student saw this as essential for clinical decision-making. This appears to be a network or web of several troublesome and non-troublesome concepts which are transformative when put together into practice and are allied closely to the EBP overarching practice threshold concept. Experts saw this as an essential element in the transformation with WTP to the threshold practising as an EBP clinician. So, this should be considered to be one of the conceptual transformations that assists WTP transformation in EBP clinical practice.

Sub-concepts 3: Screening and Diagnosis

This knowledge area is of central importance for medical practice and is mostly taught in undergraduate curricula, but this teaching seems to have varying effectiveness, possibly due to its troublesome nature (Ahmadi, Baradaran, & Ahmadi, 2015; Jamison, 2005). The competent-level student (Case 5) talked in detail about a perceptible shift in her way of thinking that marked complete understanding of this concept as clinical practice. She spoke of this in relation to the difficulty of understanding screening and diagnostic principles and definitions; how she had trouble remembering what these meant and how to apply them. She discussed how tutoring students in the Indigenous scholarship program helped her own learning during her third year. However, it was experiencing the clinical application of the concepts of diagnosis and screening in the hospital environment that helped her to truly understand it. Observing the application of these concepts in a real-life clinical setting was a tipping point in her learning so that she felt that she could at last truly understand it:

> I think that when we're first encountering these concepts in the first and second year, because everything is so new, especially the examples that you are using take a lot of brain power to get through. Whereas now, if I was to listen, if I had no understanding of the medical situation, I'd feel much more comfortable with it, because I would be able to understand the examples. (Case 3, Interview 1)

Similarly, she realised that in understanding diagnostic testing in renal physiology, she had previously simply rote-learned the various key facts. She found that she only truly understood the full process and how this depended on understanding holistically the underlying medical science and the clinical pathology when she finally researched and wrote up a renal clinical case in 5th year (Case 3, Interview 2).

All experts and the higher-level students (beyond second year) emphasised that the clinical interpretation and application of screening principles are absolutely vital for practice:

> So, it is again, a special concept at different level. But looking at our graduates, they need to understand it to convey it to the patients. This is their need. It's not doing the calculation. It's understanding it. (Expert 7, Paired interview)

In conclusion, my data confirmed that there are threshold concept elements in the underlying principles of how to apply evaluations to patients. This is transformative when practiced as part of EBP clinical practice.

Step 5: Assessing

Assessing the whole EBP process is the final Step of the EBP cycle. This is the evaluation of your management of the patient and evaluation of one's own EBP practice. Clinical audit is one mechanism for doing this at individual level or on a larger scale. This EBP step is deemed a separate competency by Albarqouni et al (2018), under the title of "Evaluation" which interestingly states that the ability to practice EBP rests on "overcoming individual barriers to knowledge translation" and having strategies to overcome these (5.1). It also includes the personal clinical audit, emphasising that this is "comparing own practice to standards" (5.2).

During the abductive analysis, data themes didn't arise explicitly around students' assessment of their own EBP practice, probably as they had not really developed this practice as yet. However, analysis of the data showed that more competent students understood that its contribution to the EBP cycle was essential for further self-learning and for refining patient care. Overall, reflective practice was a theme that was strong across the participant groups due to the reflective nature of the study they were taking part of, and due to the emphasis on reflective practice across our medicine curriculum. Students were keen to invoke their reflective skills in practice during the data collection activities, and also to talk about how reflection aided their learning. Self-evaluation and reflection were a major theme for student cases when talking about the practice of information skills and critical appraisal. More mature students mentioned that their confidence increased as they gained EBP skills and practice, this stimulated a more active review of their EBP practice – leading to a positive cycle of improvement. Within the literature, there is little published about this EBP step in terms of learning. However, reflection and self-evaluation of learning are anticipated components of medical curricula these days, so it could be expected to be explained and learned well as a generic skill for application as a key element of clinical practice.

In applying the TCF and associated models to the data and literature, this step appears transformational and integrative for some students. Clinical experts considered this to be part of their usual clinical practice, but there was limited reference to this from other participants. Applying the K-S-M model (Rountree et al., 2013) revealed that this step requires knowledge and strategies for good practice. Also, mental models appeared useful but are likely to be self-taught as an intern as a necessity of their intense learning curve toward clinical practice. In terms of expertise, those with more practice and higher-level expertise of EBP were able to practice this more easily and more likely to see it as important. Viewing this using the revised Blooms taxonomy, it appears to fit with the highest level of practice; requiring metacognition as evaluation of one's own appraisal. Interestingly, in my original threshold concept model for EBP and Biostatistics, I did not mention this step explicitly (Quinnell & Thompson, 2010), possibly as I don't actively teach in the clinical placements, so missed its importance in my model. In summary, Step 5 of EBP appears to meet the characteristics of a threshold concept for some but not for all learners. However, it appears to be an inherent part of the overall practice of EBP in the clinical environment.

Summary: EBP as Conceptual Learning

This section presented the data analysis and alternative casing process findings for EBP. It has identified some high-level overarching threshold concepts and practice, all the way down to simple, non-transformational concepts. There were other concepts that were not deemed troublesome or didn't appear important to a few of the participants. An analysis summary of all the main concepts identified is presented in Appendix 4.2. The next sections present the findings for research and medical biostatistics.

4.2.4 Conceptual Learning in Research

The flipside of learning about putting evidence into practice is that students might miss out on understanding research as an intellectual and collaborative practice. In fact, research is identified as another overarching threshold concept, with many sub-concepts, key principles and allied concepts that need to be understood for the full transformation and for thinking like a researcher. As shown previously, it is vital for a modern-day doctor or healthcare professional to learn how to use evidence for practice, but also how to be a researcher. The following are concepts specifically identified by more than one participant within the thesis data: data as a concept; understanding study design; statistical analysis and interpretation; applicability (clinical significance); external validity (generalisability); internal validity (application of study quality and bias); bias in research; and the research approach (e.g. qualitative and quantitative methods). See Table 4.2 above for summary details.

Research: Study Design

Study design was not raised as a troublesome concept by experts, but was identified as definitely troublesome, if not transformative and irreversible, by several of the student cases. A first-year student found a specific aspect of randomised-control trial (RCT) study design to be a threshold concept. He described how he came to understand how recruitment bias could affect the whole validity (generalisability) of a clinical trial using contextual scenario examples:

> *Particular examples from various randomized controlled trials, such as differences in the socioeconomic background of subjects helped to elucidate that concept for me. Further additions to my concept building included how other perspectives such as the location which acted as the source of recruitment such as a hospital could adversely affect the generalisability of results.*

More authentic examples stimulated his learning:

> *The tutorial proved to be extremely helpful because it discussed seemingly abstract scenarios in the context of a real-world scenario, i.e. in the context of a possible RCT. I believe it easier to understand such a new, threshold concept if an unacquainted student can relate them to an actual scenario.* (Case 1, Journal)

It is of concern that the experts lacked insight into this being a troublesome topic for students. In the old-fashioned traditional medical courses, epidemiology was taught as main content in a course in later years and focused considerably on study design. In contrast, the integrative curricular design at UNSW has spread out epidemiology topics across the early years of the program, and this has possibly fractured the student learning process. Fortunately, this is taught explicitly in the QMP curriculum in the first course of the first year. Thus, a student's ability to access their understanding of these concepts during later clinical attachments becomes the key issue in clinical application of this concept.

Research: Applicability, Validity and Bias

These concepts are presented above under the EBP Step 3. They are included again within this research topic as my analysis showed that there is a slight difference between the concepts as viewed from the EBP compared to the research perspective, with the main disparity being in the terminology. In all other respects, these appear to contain similar knowledge, meaning and importance for practice.

Research: Qualitative vs Quantitative Approach

This concept was specifically identified by Expert 5 but was also touched on during the paired interview of Expert 2 and 3. Expert 5 is a clinical academic who is in the early years of a part-time PhD, and on starting this research had the not uncommon experience of finding qualitative research theory and approach troublesome, but transformative:

> For me, a recent threshold moment with qualitative stuff was just coming back to the ideas that were underlying it, the ideas of positivism versus constructivism and interpretivism and … that really actually helped me to contextualise why you do one or the other, and all of a sudden I realised all of these plans for mixing methods in studies were maybe not the right way to go, and I'd rather do things properly, separately and then have things as complementary. (Expert 5, Paired interview)

Medical training tends to focus on quantitative research, epidemiological methods and data. So, for Expert 5, encountering the opportunity to learn about qualitative methodology at a later stage in life was revelatory, as it was for me also during my early doctoral research:

> So those bigger ideas helped me to put things in perspective, so there's stuff happening within me, and I don't know if that makes everything else more visible to me, do you know what I mean? Again, maybe this has been simmering and I didn't see it happening before now. (Expert 5, Paired interview)

Supporting this view is research on post-graduate doctoral candidature that agrees that taking a theoretical perspective (Kiley, 2015) and using a qualitative approach for the thesis (Humphrey & Simpson, 2012) appear to be threshold concepts. This suggests that for some people this transformation is a threshold in knowledge as well as reconstitutive in ways of practising research. In addition, there may have a disciplinary factor, as implied by several lively discussions where expert pairs from different disciplines were in disagreement regarding research perspective topics, compared to more concurrent views when they were from the same or similar discipline. This suggests that one thinks and practises slightly differently as a research epidemiologist, a medical scientist or as a clinical researcher.

Overall, research as a perspective or approach appears to be an overarching threshold practice, rather than a simple concept; it is transformational and troublesome at times, but once achieved it is a marker of disciplinary expertise when fully integrated with the relevant disciplinary approach and it becomes a way of thinking and practising.

4.2.5 Troublesome Concepts in Medical Biostatistics

Medical biostatistics is biological statistics with a medical perspective. Understanding statistics is acknowledged as a key element of the core EBP competency of critical appraisal (3.0), with specific mention of: "3.2 Interpret different types of measures of association and effect, including key graphical presentations" specifying a practical understanding of data, basic frequency measures, and the difference between "*statistical significance* and *importance*, and between a lack of evidence of an effect and *evidence of no effect*." Also, "3.4 Critically appraise and interpret a treatment study," specifying a practical understanding of "measures of effect" and "measures of uncertainty" (Albarqouni et al., 2018).

Biostatistics: Sampling, Data, Distributions and Summary Statistics

These key concepts are presented together as the data suggested that they are inextricably linked. Regarding summary statistics, Expert 1 was candid about this:

> …when you're trying to describe a large group, you can do that very effectively with one or two summary statistics from that sample. Like a mean or a proportion or something like that. The second concept is that it's much easier to compare two groups or three groups or however many groups with each other, using those one or two summary statistics. And the third step, I think, is that those … summary statistics, which describe each of those groups, have distributions. (Expert 1, Interview)

All experts identified these as threshold concepts, but students were hazier in their reflections. The experts' opinion was that these statistical concepts are troublesome to learn, irreversible once understood, integrative, and bounded within the relevant discipline. This aligns well with current research into their status, that these are the most easily identifiable troublesome statistical concepts (Norton, 2015). Their linkage is key to their transformational character and this is discussed in a later section.

Biostatistics: Central Limit Theorem

Another fundamental concept that often feels too advanced a concept for teaching in a basic biostatistics course is the *central limit theorem* (CLT). The CLT derives from a complicated proof and states that from any population, under most circumstances, if you take multiple samples, then plot the mean of each sample, the distribution of the means will be normal, even if the original variables are not normally distributed. It is a vital proof supporting the fundamental process of inferential statistics. It is backed by other theoretical assumptions, such as the *law of large numbers* and the *standard normal distribution*, which are troublesome conceptually as well. Utilising the unique characteristics of the normal distribution, it provides a way of making probability estimates for the range that sample and population values might take.

Few students mentioned this concept, but interestingly experts avoided it also (which might indicate that they find it hard also). This first-year student's reflection sums up what was found in the data:

> *I don't understand the central limit theorem nor its use currently. The threshold concept of focus here is integrative where I know both A and C but cannot find the link B between them. Also, the technical nature of the definition makes the troublesome knowledge also relevant - perhaps need to solve with my own definition in layman's terms followed by this formal definition.* (Case 6, Journal)

This concept has been identified as a probable threshold concept across the literature on the teaching of statistics and biostatistics (Dunne et al., 2003; Meyer & Land, 2005; Quinnell & Thompson, 2010; Wills, 2017). Wills' findings from his comparison of academic and student experiences (2017) suggest that it defies further examination as few experts find it easy to understand themselves, so they shun further educational research or effort into this topic. This is backed up by my brief exploration of several old (1950-1970) statistical textbooks comparing these to my newer statistical textbooks (1990-current). This revealed that the topic of the CLT is less likely to be explained for student consumption now, than it used to be. This is an easy teaching solution to a troublesome topic: evading the detail and compressing it into a simple definition for digestion, but not detailed explanation for full comprehension. This is a good example of avoidance in teaching of a very troublesome, possibly threshold concept by both teachers and students. Baillie et al (2013, p. 234) consider that over-simplification of a complex concept can make it more difficult for students later on; they emphasise that the "critical features" of a threshold concept should be taught early on and built upon later.

Biostatistics: Degrees of Freedom

Most students early in their statistical learning shy away from the concept of degrees of freedom as it has all the hallmarks of being 'too hard'. However, it is necessary to understand this as it influences how statistical tests are applied. So, when I introduce this topic in class I mention that this is an advanced and difficult concept. One student case admitted that they tried to understand it and failed. He touched on this when discussing transformative events realising that "it" (the transformation) "has to happen" for degrees of freedom to be understood but stating that: "I haven't sorted out that one yet." He continued to try to explain but didn't seem really to know why this might be the case: "…because it's a bit too abstract for me or something" (Case 2, Interview 1). Later in the first semester, this student wrote a whole journal entry on this topic and explained how he had tried and again failed to make headway with understanding the concept, writing of moments of doubt and "self-defeating thoughts," and in the end he admitted that he almost convinced himself that he had better things to do. However, he persevered in his study, finding three very different resources that failed to help. The final resource was a long piece of explanation found in a website that finally defeated him:

> *My brain was fried trying to process the paragraphs. Along the path of trying to understand the concept, I didn't discover the piece of the puzzle that would resolve it all.* (Case 2, Journal)

I was impressed by his tenacity however, as he signed off with a positive: "I will resume later." This echoes many of the students' journals that speak of failure but contain an element of determination (or hope) to understand eventually. This deferral strategy and other common student responses to encountering of troublesome concepts will be examined in more detail in Chapter Six.

Biostatistics: Hypothesis Theory, Significance, Confidence Intervals and Effect Size

Vital concepts that experts identified and appeared to flummox students early on in their medical curriculum were the ideas of hypothesis testing, statistical tests and significance. Expert 7 was clear in identifying these as a common, important stumbling block for students:

> …and the fact that most of the statistical procedures that they are doing is about testing the non-hypothesis and not the hypothesis, is a major component. And again, it is all about the concepts of statistics that it is hard for them to understand. (Expert 7, Paired interview)

In addition, Type 1 and 2 errors were identified by Expert 1 as "at the heart of hypothesis testing" (Expert 1, Interview). Students also mentioned these principles, mostly in their journal entries, for example:

> *I get confused easily whenever I hear the term null hypothesis. Not because I don't understand what it means, I do; I have trouble visualising what a phrase containing the*

term actually means. ... The relationship between type I error and type II confuses me. (Case 2, Journal)

Fortunately, this student continued with his reflection, detailing his struggle with the concepts and his use of several different resources and self-reflection, until he finished with a good explanation of these inter-connected concepts, and a comment showing that he was approaching a threshold of understanding:

> *To be honest, my grasp of the topic is still shaky but somehow, I am confident I am on the right track. Hopefully, I am correct in my confidence.* (Case 2, Journal entry)

Similarly, the concept statistical of significance (as statistical significance expressed as P-values and as confidence intervals) was universally identified as troublesome in the expert interviews. The experts' ways of explaining the importance and troublesome nature of this concept again was varied and appeared to depend on their teaching approach: statistical, epidemiological, clinical. For Experts 4 and 5, this was a major discussion point. Expert 4 explained further:

> I think it's a clear transformation to understand that statistics is the quantification of – it's in essence the quantification of the probability of something being true, and it can only operate in the pure sense if the research is unbiased by whatever the response. And once they understand that, then they understand why the P-value isn't telling them the answer to the question they want to answer. (Expert 4, Paired interview)

Similarly, Experts 6 and 7 agreed that the P-values and the theory behind this (i.e. sampling and hypothesis formation) is very complex. During the analysis, an unanticipated finding was how the experts identified similar linkages across the threshold concepts for sampling and significance, relating these via the null hypothesis and distribution elements. Indeed, fundamental sampling concept appeared a key element of significance: "…but teaching P-values I think also depends on that sort of – well I'm not sure which is the threshold concept necessarily. But I think P values and the confidence intervals all rely on that idea about sampling variability" (Expert 6, Paired interview). This conversation of two statistical experts continued along this vein, with Expert 7 identifying a further element regarding the formation and testing of the hypothesis as pivotal and making links between them. They continued this discussion with an explanation that took it beyond hypothesis testing to the next two steps of interpretation of the results, involving concepts of effect size and statistical significance:

> For example, I believe that very few students and even quite a few staff or academics, understand the meaning of correlation. … If you've got a correlation, say, of 0.4, it means

that the variance explained is 16%. But they don't realise that it means that 84% of the variance is not explained by that correlation. And this is the major lack of understanding... Not just what it explains, but what it does not explain. (Expert 7, Paired interview)

Surprisingly, regarding these concepts around significance, the student point of view was similar to the experts in that they were certain these were troublesome and transformational, but they were less certain that they actually understood the complete concept. For example, Case 2 thought that he had understood it, but he was quite wary about committing himself to having a full understanding: *"Okay, we need to compare what is significant, whether these results agree or not, or this is something that's random. I can get the sense of what's the concept all about (sic)"* (Case 2, Journal).

Overall, these findings show that all these concepts are troublesome for most students, and most experts and students considered them to be transformative. Indeed, the sense from many participants was very strong that understanding these created considerable 'eureka' moments for them. These findings are similar to recent research in statistical conceptual learning using different techniques to reveal the troublesome and threshold concepts. The concepts required to understand statistical significance were most often identified by students as a key sticking point in their learning, independent of the disciplines within which it is being taught (Bulmer, O'Brien, & Price, 2007; Downs & Robertson, 2015; Wills, 2017). Indeed, agreement of my findings within this non-medical statistical literature indicates that published teaching approaches for improving this learning process from this source, might also be effective for medical students.

Summary: Conceptual Learning in Biostatistics and Research

Troublesome and transformative concepts and other conceptual forms were identified in research and biostatistics in a similar way to those in EBP. There were several over-arching threshold practices and also transformational threshold concepts identified, which relate well to published research findings about general EBP and statistics. The next section presents the next phases of the abductive analysis – drilling down into these troublesome learning points to find out more about how these concepts fit together and interact in order for us to learn to think and practice in undergraduate medicine.

4.3 CONCEPTUAL LEARNING AS A SYSTEM

The final stages of the iterative abductive analyses using the Vygotsky-TCF framework for conceptual learning centred on the transformation and troublesome points identified in the interviews and submitted reflective journal data. This revealed further discoveries into how these conceptual forms link up, network and collaborate for transformation, reconstitution, integration and practice.

4.3.1 Everyday Concepts and Knowledge Building

The Vygotskian perspective of spontaneous and scientific concepts was applied alongside the TCF to all the interview and journal data. This resulted in important revelations and findings relating to the Vygotskian conceptual theory and the classification of conceptual learning in the TCF. The first interesting finding was that experts were able to identify concepts readily and also to ascertain the difference between the spontaneous concepts, tacit knowledge required for understanding, key disciplinary academic concepts and threshold concepts. The following examples demonstrate how the experts understood that 'everyday thinking' and previously learned scientific concepts took part in the building of more complex scientific concepts, and for explaining and linking more complex concepts. Their comments were expansive across the interviews with comments frequently touching on the tacit knowledge expected of their students. For example, regarding statistical distributions, Expert 1 showed some understanding of the distinctiveness that the troublesome knowledge has beyond everyday tacit knowledge:

> And that's now a bit more of a difficult concept, because it's not something that people deal with in their everyday thinking. (Expert 1, Interview)

Moreover, in a paired interview, the clinician with more statistical and EBP teaching experience was very clear that everyday thinking is linked to current word signification, which can be both a hindrance and an assistance to learning statistical concepts:

> …that's almost a separate threshold moment, it's absolutely related to clinical significance… – it's because of the use of the word significant. They think they understand what significance is and they're seduced by the whole thing with the 'P' less… and all that sort of stuff, and that's all baggage which prevents them from understanding what people mean when they say *clinical significance*. So, you use a metaphor, or you use alternatives like 'does it matter for your patient?' They understand

> that alright, but they can't quite work out that it's the same thing. (Expert 4, Paired interview)

This appears to be a case of the students' everyday understanding of 'significance' interfering with their learning of the scientific concept of 'significance'.

These initial findings stimulated further research to determine how this related to Vygotsky's ideas of spontaneous and non-spontaneous concepts, and systematised conceptual networks. During the next wave of analysis, I noticed that Expert 1 had pointed out that information literacy might not be a threshold concept, but that he considered it to be complex and requiring a step up from basic everyday (pre-academic) practice:

> [I] don't know whether that makes it a threshold problem, but there are several aspects that you need to get together at the same time and because they're not part of our *everyday* life, like information gathering in evidence-based practice for example... (Expert 1, Interview, emphasis added)

Also, it was interesting that first-year students appeared to be less able to see the differences between the everyday, spontaneous and new academic concepts so clearly. However, there were some small nuggets of enlightening data, for example a second-year student reflected on his learning of a basic statistical test and wrote an aside to the chain of thought he was taking during revision later in the year:

> *[uncomfortable - knowing that I have been exposed to the concept of t-test from high school, I still don't have the same understanding the same way I understand that one day consists of 24 hours. There's a mental click inside my head whenever I encounter something I don't completely understand].* (Case 2, Journal)

Through the discomfort that he felt when this 'click' in his head happened, this student was made aware that he still didn't understand this concept adequately enough. He went on to explain that he realised that he did not understand it in the way that an everyday concept such as the "number of hours in the day" is just there and conceived automatically in his mind. Therefore, it appears that this student has a useful metacognitive strategy for confirming whether he understands a new concept, based on the level of discomfort he feels and/or the extra thinking effort required to understand it.

The idea of everyday knowledge being a major part of conceptual learning appears very important. The literature on the 'everydayness' of threshold concepts takes an interesting perspective on this. Shinners-Kennedy (2008) explains his theory that many disciplinary threshold concepts are built on everyday concepts or even are everyday concepts. By "everydayness," he means the layered or compressed knowledge that is learned and becomes automated for everyday living and tasks (Shinners-Kennedy, 2008, p. 120). This corresponds to the "ritual" or "inert knowledge" that Meyer and Land (2003, p. 6) mention in their classic explanation of troublesomeness. In that example, the inertness of the everyday knowledge that is being used for further learning in a threshold concept is troublesome as it is too well known and even meaningless or unnoticed. Inert knowledge is so well assimilated into understanding and usage that it is difficult to see, or unpick, or view it in a different or new way.

In a similar way, Vygotskian spontaneous concepts can be deemed equivalent to the tacit knowledge mentioned in the TCF literature and within the expert and student interviews. Early in the development of the TCF, the key proponents all mentioned that the underlying, previous conceptual knowledge, that often goes unacknowledged by learners and teachers, was important for knowledge building and also for knowledge reconstruction (Meyer & Land, 2005). The theoretical framework for this thesis suggests that the tacit, everyday learning is transformed by academic instruction via a process of 'letting go' and reconstruction, based on both Vygotskian and TCF ideas about the conceptual ontological process. Considering Vygotsky's theory, it was interesting to find that my analysis resonated with his idea that some developmental conceptualisation might be transformational and appears to suggest that this is a necessary step to expertise. In Vygotskian terms, when spontaneous and non-spontaneous understandings connect in the learner's mind to become grounded, newly fully understood and concrete, these internalised concepts appear equivalent to the integration and irreversibility mentioned in crossing the liminal threshold in the TCF. Furthermore, Vygotsky postulated that this leads to mastery at a higher-level following reconstruction of the conceptual understanding and new meanings being forged (Vygotsky, 2012, p. 203). I will demonstrate how extrapolation from this theory to the TCF and onto the students' transformative learning journeys supports the idea that newly learned individual concepts should not be isolated from concepts already present within the mind, but need to be internalised and assimilated with them into a new conceptual system to gain more solidity and permanence. It is during this process that the transformation in knowledge and belief seem to be most likely to occur.

4.3.2 Knowledge Transfer into New Learning

Exploring how current conceptual knowledge is used in new learning is vital to understanding the conceptual learning process. Interestingly, this tacit knowledge was easily detected in the data. Students were aware that basic concepts (even from other disciplines) assist in understanding a new concept and their associated networks. A good example was given by a first-year student case discussing the learning of statistics at high school. He remembered how he had transferred statistical conceptual understanding from a mathematics course across to statistics in biology, and how this benefitted his understanding of the concepts in both fields:

> We did the normal distribution and the binomial distribution, and that, sort of, reinforced the concepts in biology and, sort of, made it a lot easier to understand and comprehend what was going on in my biology class, because I was able to relate the concepts regarding the health sciences with my mathematics. So, when you actually get to get the concepts reinforced in a related subject, that really helps in building your concepts from the grass roots of it. (Case 1, Interview 1)

Understanding he could learn better by concept transference was a sign that he was post-liminal and was now able to transfer this learning to other concepts. This became a useful tool he used for later learning: "it wasn't problematic at all, because I already knew the concept beforehand, …" In particular, it was "being exposed to the very basic principles of analysing data and biostatistics" that helped the most and made "a lot more sense" of the new learning as he found that he a sound understanding already (Case 1, interview 1). Hence, this student has arrived at university with a successful learning method, derived from early transformative learning experiences, and this ability to transfer skills and knowledge across disciplinary subjects was recognised as useful for his future studies.

Implications for Teaching and Learning

Further research needs to be done to confirm and elucidate the various elements at play here, but these tentative findings suggest that identifying the various spontaneous concepts/tacit knowledge underlying or present as building blocks for troublesome concepts could assist students in their learning of troublesome scientific/threshold concepts. Perkins and Salomon (2001) argue that the ability to transfer skills and knowledge across disciplinary learning is essential for effective learning in higher education. Furthermore, Hattie and Donoghue (2016) support this as part of an effective learning strategy which involves three phases of learning: surface, deep and transfer. They imply, alongside others, that transfer skills should be taught to enhance student learning (Halpern, 1998; Hattie & Donoghue, 2016; Perkins & Salomon, 1992). The important role that analogy and narrative plays in drawing on previous understanding for conceptual learning, is discussed in the next chapter.

4.3.3 Effect of Knowledge and Expertise Level

Participants did not yield consistent reflections and experiences regarding conceptual learning and transformation and neither experts or participants found the study process of reflection in the in-depth interviews or the written journals easy. It was clear from the way that participants spoke and wrote these reflections, and also from the relative amounts of data available, that students found it harder to identify specific troublesome concepts, than the experts. First and second year students found it harder to identify the underlying, previous knowledge or skills that they had prior to this (prerequisite, underlying concepts and tacit knowledge or skills). Additionally, they found it harder than more mature students to describe what had assisted and/or frustrated their learning of these concepts. Similarly, experts found it easy to identify the major disciplinary concepts but were able to provide less detail regarding the actual learning process. There were similarities and marked differences noted in the individual concepts that were identified by participants, and also the way in which the different participants discussed the learning of concepts. In general, experts had less trouble identifying and agreeing on the major transformational concepts, whereas, student novices provided more detail about the actual experience of being in a troublesome learning moment but were less able to clearly articulate which concepts were transformational or changed their personal perspectives. Predictably, students found this much easier after they had passed through the liminal space or transformational moment.

This variation in findings between the experts and students is an expected phenomenon, well-documented in the TCF, the expertise and conceptual learning literature; experts forget what it is like to learn a difficult concept as they move on rapidly onto the post-transformation stage and beyond. Learners who are past the transformation point are able to look forward to the new horizons that this new perspective allows them, but their view back to where they have come from is necessarily restricted by the change that has occurred (Land, Cousin, Meyer, & Davies, 2005). In contrast, those experiencing the troublesomeness of the liminal space will know that they are stuck in it, but may not be able to see far beyond it or even that far ahead of their current stage of learning and understanding. A succinct example of how this can prevent clear understanding of past learning came from a first-year student, regarding the learning of maths concepts at high school:

> And that's the problem because when I explain something some things are so hard to explain because you need to have the foresight to realise that in two seconds' time you have to have hindsight. I find it so hard to explain. (Case 8, Interview 1)

This presents the student, the teacher and the researcher with that ever-present problem of being unable to view conceptual learning readily, which can impinge on the quality of teaching and studying. Evidence from the TCF literature concurs that it is best to use both the expert and the student experience in mapping out threshold concepts, being mindful that students' language may not be as clear as the expert, and that the expert may not remember the learning difficulties or process as well as the student (Meyer & Timmermans, 2016). This is now the prevailing approach used for threshold concept identification. The Vygotskian view of this process is somewhat different but has parallels to the TCF here. The Zone of Actual Development is where the student's development has matured fully, being "the 'fruits' of development" (Vygotsky, 1978, p. 42). At this stage she is capable of independent application of this knowledge and understanding. This zone is where the student has mastered the knowledge adequately and can apply this independently but with varying degrees of consciousness of the processes involved depending on the level of conceptual mastery. The higher consciousness of the concepts and generalisations are reserved for the more experienced student. As Langford (2005) expresses it, consciousness arises "from the existence of system in the external social world and the presence in the child of enough maturity to benefit from it" (p. 102).

Implications for Teaching and Learning

Together these findings suggest that the various learning experiences and different levels of discipline expertise of the participants are produce the disparities between the more expert participant compared to the novice. This has implications for research approaches, as previously noted in the TCF literature, and it has repercussions for teaching. Targeting learning at the correct knowledge level and identifying the troublesome concepts and their specific nature could assist in the learning progress of students, essentially echoing the Vygotskian-derived teaching approach of scaffolding, as advocated by Hammond (2001). Another point here is that the discursive nature of the expert interviews encouraged useful, open discussion around the concepts identified, which resulted in the experts not always agreeing on the concepts identified by their pair, or their peers in other interviews, or as presented in my threshold concept analysis of EBP and Medical Biostatistics. This led to a further analysis exploring these disciplinary boundary lines (see section 4.3.6).

4.3.4 Integration of Concepts for Disciplinary Learning

It appears to make perfect sense that, in terms of our thinking processes, concepts link up and that our learning of key disciplinary understandings relies on visualising the networks that these concepts make. However, the theory behind this is conflicting. This section confirms research findings, explores the theory on conceptual networking and identifies networks mentioned in students' reflections. Further, it examines whether learners and experts are aware that these key disciplinary concepts are learned as part of a conceptual system. It discusses the significance of understanding concepts within internalised systems and examines how the students believe that their learning approach and the teaching support that they receive can help or hinder this process.

Network Concepts Confirmed in the Data

The most surprising finding in searching for conceptual systematisation was that concepts were rarely seen as isolated by the students; they are aware of a linking effect between related concepts, but often miss seeing them when they first encounter them. Experts identified the existence of conceptual links but the short interview time available limited their identification of how these concepts might network or how students might better approach learning these complex conceptual formations. Two key themes arose from the analysis, that related directly to conceptual networks, "Network of concepts" (under "Threshold concepts" theme heading) and "Mapping or creating own pathways" (under "Critical Thinking" theme heading). The threshold concept definition term (provided to participants) of "Integration" was used alongside these two new themes in the abductive analysis for coding the data.

Expert Perspectives

A universal understanding was expressed within the participant data for the difficulty of teaching and learning threshold concepts in statistics with the main challenge being seen as the bringing together of "several concepts that need to hang together, to get you through the whole flow of the argument" (Expert 1, Interview). As previously discussed, this expert identified some essential links between the key concepts that (for him) make up an overarching, transformational sampling lens. Altogether, the troublesome aspects of teaching were attributed to the complexity and difficulty in identifying the necessary conceptual networks for student learning in the curriculum. There was indirect reference to scaffolding for learning, with experts across all the interviews discussing that concepts should be introduced in exact sequences for maximal student learning opportunity and to assist in the layering of conceptual understanding. Expert 1 explained that undergraduate medical students find Biostatistics and EBP especially hard as they are young and inexperienced in life as well as medicine. He suggested that it is hard for teachers to keep the content relevant to students and at the same time give a holistic view of the concept. This finding confirms the previous section's argument that exposure to everyday, tacit, inert and ritualised knowledge is important for this higher-level learning.

Interestingly, experts spontaneously touched on the question of whether the exact integration moment of key concepts is the actual threshold transformation moment. For example, Expert 1 thought that when all the concepts come together, is when the student can "start to see the whole picture."

> That's a threshold problem for me. And I don't know whether that makes it a threshold problem, but there are several aspects that you need to get together at the same time and because they're not part of our everyday life, like information gathering in evidence-based practice for example, and information literacy skills... They're not the sort of things we do every day for thinking through the logical steps of statistics. (Expert 1, Interview)

Additionally, Experts 2 and 3 argued that there is complexity in single concepts and, further, they conjectured that there must be systematised conceptual networks. They noted that they teach some concepts in a specific order so that students can understand more complex concepts later. Also, they could see links between certain concepts and explained that they use these links as learning points to aid the students' transition into the next conceptual learning area. This was an especially interesting aspect of this paired interview as it identified the linkage of concepts as one of the key troublesome aspects of teaching biostatistics.

Student Perspectives

The student case interviews and especially the reflective journals provided excellent data for this analysis. Student cases talked about "juggling" concepts or trying to "piece them together," and also mentioned the need to break complex concepts down in order to build them back up again. For example, a first-year student (Case 8) viewed conceptual learning as a web of concepts that linked up. He described early encounters with concepts as difficult, as students don't necessarily see how they fit together, as explained in this interview thread:

> You have to do it the right way. I think, introduce this whole thing in the right direction and then it eases in. But if you're really fragmented or if you go there without explaining another concept it's much harder.

He went on to explain how he sees his conceptual learning network as a web with different complexities depending on where he comes into it:

> It's like if you have a web. On some points there are lots of little junctions but on some junctions, let's say, if there's only threads crossing it, I think it's better if you start from what has few threads then you work your way out. But if you start picking up the one in the middle with lots and lots of junctions it's too hard. …To explain this point, you need to explain the other 10 points at the same time.

His analogy of the spider's web seems to describe how it is simpler to start at the edge or less complex points when learning and move inwards to the more intricate centre, than start at the centre and move outwards. Later, in same interview, he paused and said:

> It's been boiling back of my head. It's revisiting the whole thing also helps out. It's like with a spider's web, you do one layer, right, until you have the basic framework and then once you have the entire framework you revisit from level zero, you go back to the start again then – as a learner, okay? (Case 8, Interview 1)

He has developed his previous example further by explaining how new concepts are laid on top of old ones in the web. Taking this further, another first-year described how he thought that the concepts linked up across the disciplines to help his learning:

> *Linking the dots between medical disciplines is also very important, and something that UNSW's medical degree focuses on. Subjects such as anatomy, physiology and histology can overlap significantly, hence learning in one discipline can improve understanding in other.* (Case 7, Journal)

These reflections suggest that students can sense that the knowledge and perspectives that they are studying are inextricably linked up and that learning these together, holistically can assist this process. Later in the year, the same first-year student summed this up clearly, when he considered this process of linking up to be a form of layering of knowledge as if he is building a brick wall: "*Learning in this integrated way also helps you to build up your knowledge and put layers on your knowledge, as if your knowledge* *is a brick wall which you keep adding layers to"* (Case 7, Journal). This suggests that he saw his learning building up from the bottom row of concepts to make something substantial and solid. Interestingly, this is very different to my own idea of my conceptual network (as an expert), which is more dynamic and fluid, with movement and flexibility built into the system.

Integration and Perspective Shifts

Further analysis shows that the linking up or integration of concepts into more complex concepts or networks or overarching concepts can be transformational in terms of a perspective shift in understanding (epistemological), and in being (ontological). The fifth-year student put this most succinctly: "I think it's almost in the perspective in which I see things, I think I categorise things and see the relationships between things, and then once that's clicked, it's that perspective in which I see it" (Case 3, Interview 2). This use of categorisation in learning appears to be one of the key skills that students use to break down and then build back up into their new conceptual way of seeing things. Importantly it is one of the defined critical thinking skills from the consensus that was provided to students (Facione, 1990). Expert 2 agreed:

> … maybe to understand sampling you don't need to know just one of those, you have to be able to understand all of it really to get it or not? (Expert 2, Paired interview)

A second-year student, also felt that the integration was vital for full understanding:

> So, … when you put it all together it all makes sense. I guess that's when that 'eureka' - you see the whole instead of just the parts. (Case 2, Interview 2)

For the fifth-year student, practice in applying the multiple threshold concepts for fluent critical appraisal ability during the earlier program years was integrative:

> I mean, for example, when we do assignments and case presentations, … you're kind of glad for having developed good critical appraisal skills. I feel like when I judge a source, I don't have to think so much about it, I'm already thinking about who wrote it, and what kind of biases [are present]. (Case 3, Interview 1)

She had come to realise and be satisfied that she was finally fluent and competent in critical appraisal.

Theoretical Considerations

Vygotsky described the need for concepts to link up for effective thinking, as they can't lie like "peas in bag" (Vygotsky, 2012, p. 209). As previously discussed in Chapter Two, Vygotsky suggested that the conceptual movement occurring across the coordinates of the globe is "paths of thought" within a given semantic field (Vygotsky, 2012, p. 211). This idea of a self-organising system of conceptual thinking seems radical even today but proved useful in my endeavour to distinguish in the data how the students' concepts connect, revise, reform and synthesise during their learning. The current learning theory that comes closest to this is the relatively new and widely embraced constructivism (Fosnot, 2005), which is supported by Piagetian theory. Furthermore, Howe (1996) argues that the merging of Piagetian constructivist and sociocultural Vygotskian approaches is possible and provides a valuable constructive framework with which to: "coordinate sociological and psychological perspectives of classroom life and can serve to free research of narrow theoretical constraints" (Howe, 1996, p. 47). This proved to be a useful lens through which to analyse the data at this stage.

Comparing the Vygotskian semantic and conceptual systems with the current threshold concepts models, there are clear similarities regarding the conceptual systematisation and networking. By visualising disciplinary learning in terms of mastering a conceptual network it may be possible to map out how academic learning necessarily engages integration and reconstitution of Vygotsky's (2012, p. 211) "subordinate" and "superordinate" concepts into new and larger concepts and threshold concepts. Indeed, as demonstrated later in the third intersection (Chapter Six), the maturing of these conceptual networks is one of the major characteristics of the learning that occurs within the ZPD and also the transformational liminal space. Later, with reference to Vygotsky, I will argue that it is this systematisation that enables the learner's metacognitive processes that are essential in the transformational conceptual learning journey.

Implications for Teaching and Learning

In considering the dynamics of the learning process, Vygotsky developed the idea that the less formed, socially learned spontaneous concepts are remodelled during interaction with school instruction that introduces and supports the learning of academic (non-spontaneous) concepts. This is almost identical to the TCF's learning hypothesis of the need for a learner to unlearn or discard or reconsider previously learned concepts and the conceptual systems that they lie within, prior to taking on new, higher level (threshold) concepts (Land et al., 2010, p. xi). This hypothesis of the rejection of previous conceptual understandings to allow new understandings, is essential to both Vygotsky's ZPD transformation and the TCF proposition that ontological and epistemological shifts are required for threshold concept transformation. This process of the learner changing their conceptual understanding and transforming their conceptual system is acknowledged as an emotional struggle of varying magnitudes, from uncomfortable to the traumatic (Land et al., 2005). This emotional struggle takes place in the liminal space creating an uneasy or uncomfortable experience. It is arguably more than as just a "letting go" of old understandings (Land et al., 2005, p. 54). Eventually this requires a drawing down on the individual's psychological capital of hope and optimism, emotional security and resilience for the learning to continue successfully (Rattray, 2016). Once old understandings are let go and replaced by new conceptual understandings, the perspective of the learner changes, and there can be an increase in mastery and further grasping of higher-level, key disciplinary concepts. The novice loses their 'greenness', developing knowledge and also a disciplinary perspective that takes them closer to becoming an expert (Dreyfus & Dreyfus, 2005). So, in terms of teaching and learning approaches, it appears wise to follow the TCF guidelines of supporting the emotional experiences induced by the learning process (Rattray, 2016), and so better support the learner's conceptual journey through the liminal space. Further development of these findings is continued in the next two chapters.

4.3.5 Overarching Threshold Concepts

From my analysis, many individual concepts were identified, and not unsurprisingly, these appeared to group together with similar concepts that then transformed at another level of understanding. Further examination of the detailed participants' comments using a matrix tabulation revealed that these individual complex concepts could be categorised under a few higher concepts that were deemed critical, and other principle concepts that were often experienced as transformative/threshold concepts by the participants. Some of these were clearly exceptional transformational conceptual development domains that could be categorised as networks or complexes fundamental to disciplinary knowledge and expertise. Links between concepts were not so easily identified, but overarching and complex concepts were identified more easily than I expected. The overarching concepts were defined as those that act as a 'super' or 'meta' threshold concept – only fully understood when the contributory, subordinate concepts are mostly understood. When this happens a usually perceptible and emotional transformation occurs as a large shift in ontological perception takes place (more so than for an epistemological change). The data also suggested that an understanding of ways of thinking or practising was also necessary for this transformational integration at this meta level.

This idea has been mentioned in the TCF in various disciplines, for example: sampling in statistics (Quinnell & Thompson, 2010; Wills, 2017); physical modelling in thinking like an engineer (Meyer et al., 2015); and rhetoric in the practice of writing (Blake Yancey, 2015). In threshold concept research in nursing, Martindale (2015) was certain that "… these thresholds are all, with the possible exception of critical appraisal, quite wide-ranging topics that may consist of a number of smaller thresholds" (p. 354). By contrast, my research suggests that complex concepts don't necessarily result in such a strong ontological shift in intellectual perception, but draw principles and concepts together into a larger, multifaceted concept that creates new understandings between its various sub-concepts resulting in better epistemological understanding.

Overarching, complex concepts, and concept networks were detected using participant explanations when either: 1) they provided clear outlines of where they saw links between concepts; or 2) a concept was seen as central to many others and derived understanding from the others; or 3) a concept was considered a principal, overarching concept that was essential to a student's progress towards expertise within a discipline. Three overarching, transformational disciplinary domains were identified from several waves of abductive analysis. These appear to carefully embrace and contain the main disciplinary concepts and perspectives for this disciplinary topic area and align well with the disciplinary ways of thinking and practising. These were named as follows: 1) The EBP-Clinical Perspective; 2) The Statistical Perspective; and 3) The Research Perspective.

1. The EBP-Clinical Perspective

The major transformational domain for EBP and clinical practice covered the whole of this synergistic field. As mentioned above, each one of the five steps of EBP were acknowledged (all experts and by all student cases) as troublesome for learning and applying, and that some were considered threshold concepts. Expert 1 also considered the application of all steps together as a cycle as a threshold concept. After full analysis, EBP did have the qualities of an overarching concept. This appeared to be similar to what

Experts 4 and 5 considered to be a key threshold concept – a clinical perspective for practice, or "thinking like a clinician." The two major perspectives of evidence-based practice and clinical practice were hard to distinguish – seemingly running into each other as watercolours bleed into each other on paper. From my own personal experience of becoming a clinical doctor, 'thinking like a doctor', develops with good teaching and learning experience into 'acting like a doctor', and then 'being a doctor'. Similarly, Case 3, recognised that she was in the midst of this conversion of perception to becoming a doctor. She talked mostly about how her study was bringing her previous learning into the clinical domain; how seeing clinicians diagnose or treat patients, and taking the role of the clinician herself, had the effect of bringing it all together. Expert 5 considered that for some students this could be revelatory, saying "I think there is a threshold – there is a moment there, somewhere, where people realise … they can affect the world, do you know what I mean?" (Expert 5, Paired Interview). Furthermore, both Experts 4 and 5 considered that clinical teaching at the bedside was the most useful activity to stimulate this essential clinical transformation learning experience in their students.

An overarching concept of EBP as a clinical perspective for practice emerged from the analysis of this sort of data. The ability to transfer the medical scientific knowledge taught within the curriculum foundation (e.g. physiology, anatomy, biochemistry) into clinical practice might seem straightforward to those who have not been through the clinical training. According to the study participants, they saw this as one of the principal means of becoming a clinical practitioner. The clinical experts were keen to hold up "thinking like a clinician" as crucial to "becoming a doctor." This overarching concept includes the transference of medical science and epidemiological, socio-cultural concepts within the clinical situation. Underlying all of this, as a framework lies EBP learning and skills that facilitate this into effective clinical practice. The clinical doctors interviewed as a pair said that gaining this clinical perspective is the most important threshold shift of the student's later clinical years or more often experienced during internship. Essentially, they expressed an opinion that this is what makes the student an effective and trustworthy medical professional. This application of conceptual knowledge in practice (e.g. as a clinician or medical student in learning) emerges following mastery of the concept (ontological) alongside critical or good thinking practice in a disciplinary manner, which is therefore the way of thinking and practising (WTP) within medicine. It is worth noting here that this transformation is likely to be influenced by individual “inclinations,” “sensitivity” and “abilities” (Perkins et al., 1993, p. 8), so there could be great variation in how this comes about and is experienced.

Previous research has identified that students find the learning of non-biomedical science topics hard to grasp, especially in terms of how to use these in ‘doing medicine’ (Collett et al., 2017). The problematic application of the EBP and other non-biomedical science skills into clinical practice has been specifically identified by researchers in several areas of health professional education, for example: in medicine (Quinnell & Thompson, 2010; Quinnell et al., 2013); in allied health (Hitch & Nicola-Richmond, 2017); and in nursing (Martindale, 2015; D. Roberts & Ousey, 2011; Waters, Rychetnik, Crisp, & Barratt, 2009). For most health professional students there are some transformative threshold concepts that need to be crossed and integrated together for a clinical way of thinking to begin and for experience of this to develop into the clinician’s expert practice. Together with the findings from this research, it is possible to conclude that EBP as clinical practice is an overarching concept; it is a key transformational domain which encompasses key troublesome concepts, principles and threshold concepts and leads on to clinical practice as an expert.

2. The Statistical Perspective

This over-arching perspective of thinking and practising like a statistician appears to require two major perspectives for full effectiveness: a. Sampling; and b. Understanding the Significance Perspective.

a. Sampling Perspective

This main concept of sampling as an over-arching lens was identified and agreed on as troublesome and/or transformational by all of the experts, although the clinical teachers’ emphasis was more towards the clinical concepts such as clinical significance and study bias. For example, Expert 1 told a detailed story about his “late in life” transformative experience (“it was a revelation, no question”) regarding how he finally understood the whole perspective of statistics, as it “makes it not foreign anymore, it makes it something that’s beautiful instead of being alien” (Expert 1, Interview). This revelation occurred through three key conceptual steps encountered two decades ago during a short post-graduate statistical course run by a local university. What struck this clinician as most constructive about this course was that its objectives, level of learning and contextualised examples were aimed at medical and public health staff specifically; it was highly relevant to his practice. Also, there was an excellent lecturer who explained concepts very clearly, and the published course booklet resource took the students step-by-step through a process of understanding statistics (Hutchinson, 1995). Expert 1 has kept this course pamphlet all those years and felt so strongly about its importance to him that he brought it with him to the interview to show me and scanned a key page for me to keep and review. He also cited another book that changed the way he viewed clinical evidence *Studying a Study and Testing a Test: How to Read the Health Science Literature* (Reigelman & Hirsch, 1996).

Overall, he explained that it was the combination of three underlying principles of sampling that enabled his statistical transformation: (i) how sampling works; (ii) the principles of summary statistics; and (iii) statistical distributions. Interestingly, these concepts are all within the overarching "sampling lens" as part of the threshold concept network for medical statistics and EBP that I use for my curriculum (Quinnell & Thompson, 2010, p. 152). All other experts agreed with Expert 1, Expert 6 explaining:

> So, it was introducing these ideas about hypothesis testing, about sampling variability, not just thinking about your sample, but what else might it be? And thinking back on it, it was such a great way to learn about that whole issue. …It's not just what you observe, but what else might you have observed is, I think, one of the most difficult concepts for students or anyone to learn about statistics. (Expert 6, Paired interview)

Later, he stressed this opinion further: "Well, I think the sampling variability is probably *the* threshold concept" (Expert 6, Interview 1, original stressed emphasis). Similarly, Expert 4 in conversation with Expert 5 stated:

> I certainly agree with your perception about sampling and significance. I think that … there are a few issues within this one and a few more. Now, I think it's understanding what a sample is, [this] is a key factor. Because statistics, at least the traditional statistics, is about sampling. (Expert 5, Paired interview)

However easy it might have been for participants to identify this concept as an overarching transformational concept, not one found it easy to explain how or why this concept was so important and/or difficult. This appeared to be due to post-liminal effects of irreversibility and reconstitution, thus the concept seems to be so simple once you do understand it. For example:

> And this very simple – apparently not that simple [laughs] but this very simple concept, I think is not well understood. For the students, from my experience, they look at the

> sample as the entire population. They do not understand that it is a sample of a population, a well-defined population. (Expert 7, Interview 1)

This expert went on to match almost word for word, what Expert 6 had said, that although this may appear to be an ordinary concept, it is of vital importance in understanding the essence of statistics: "So, the issue of – in general, the sampling issue is the core threshold of understanding of what statistics is. At least traditional statistics" (Expert 6, Interview 1).

In summary, all the experts agreed that teaching students a sampling perspective, or other key threshold concept, explicitly, the students can grasp statistics or EBP better:

> they can't visualise sampling, so if you can get them doing that the rest falls into place and it's the same for [confidence interval] values, if you can get them to visualise sampling the rest falls into place. (Expert 2, Paired interview)

These findings support that this as a strongly transformative, integrative and over-arching perspective, integrating other threshold concepts so that there is a significant change to a statistical perspective or way of thinking and practising.

Relating these findings to the literature, the sampling lens is very well developed regarding its characteristics as a threshold concept. Kennedy (1986) was probably the first to publish this clearly. He realised that most of his students were approaching his statistics classes, thinking that statistics is about mathematics and numbers, and hence often failed to grasp the key statistical concepts required for understanding statistics as a disciplinary approach. He argued that students need to view this topic through a statistical way of thinking – a "statistical lens" - instead of a mathematical way of thinking (Kennedy, 1998, p. 487). He described his own personal realisation of this as follows: "My own experience of discovering this lens was a revelation, akin to the experience I had when I put on my first pair of eyeglasses- suddenly everything was sharp and clear" (Kennedy, 1998, p.487). The words used by my participants in their descriptions resonated with Kennedy's clear description of his own revelatory moment, confirming that their experience was similar to his transformation of suddenly seeing through the sampling lens and beginning to think like a statistician.

b. Understanding Significance Perspective

Evidence for this clinical application concept in the student data centred around their current curriculum of EBP and biostatistics and focused specifically on the learning of the concepts and of clinical and statistical significance. Students found these concepts revelatory, but only when presented with written examples and diagrams that revealed and explained the concepts' meanings beyond basic definitions, whilst also accentuating the difference between them. The following example is from a student case who volunteered this revealing aside within a reflective journal entry:

> *(note: I love this part because it makes sense. In the clinical world, statistical significance is not enough. Clinical significance is where the applicability starts. I also love how accepting the scientific and statistical realms on the inevitability of having a sense of uncertainty in their results, in reproducing the true population effect.)* (Case 2, Journal)

This same student (Case 2) in their second interview at the end of the year, spent a long time explaining their "revelation" of this concept of clinical versus statistical significance gained by learning from the same explanatory diagram:

> …I have been struggling with this concept for quite a while because it really made no sense if a study found a particular therapy to be statistically significant, like if you do a statistical test and you find that this particular intervention was a pretty significant degree of benefit in a sample of the population but then it doesn't translate to clinical benefits. And that seemed to be a very abstract concept for me. (Case 2, Interview 2)

However, he had persevered in his study and found an online QMP resource to assist his understanding, worked it out with the help of these explanations and exercises. This shows once more that perseverance in learning challenging concepts is vital to gain that transformative shift, and that certain learning activities and resources can be supportive in conceptual learning.

3. The Research Perspective

This perspective of thinking and practising like a researcher, appears to envelop the other research-based concepts, integrating and transforming students who have succeeded in mastering it. A good example of this from the student point of view was provided by Case 1, once more reflecting on his difficulties with researching evidence for assignments early in his first-year:

> *I even struggled to understand the fundamental difference between different study designs such as randomized controlled trials and cohort studies.*

And further on, he continues:

> *I had not perfectly comprehended the concept of subject recruitment introducing bias in a trial. Particular examples from various randomized controlled trials, such as differences in the socioeconomic background of subjects helped to elucidate that concept for me. Further additions to my concept building included how other perspectives such*

as the location which acted as the source of recruitment such as a hospital could adversely affect the generalizability of results.

Clarification of these biases with an everyday context was helpful:

> *The tutorial proved to be extremely helpful because it discussed seemingly abstract scenarios in the context of a real-world scenario, i.e. in the context of a possible RCT. I believe it easier to understand such new, threshold concept if an unacquainted student can relate them to an actual scenario.* (Case 1, Journal entry)

This journal entry touches on all the key concepts that other participants mentioned across the data, namely: study design, bias (in this case selection bias), and external validity. He goes on to explain that he eventually understood the whole research element through understanding these parts, via this tutorial scenario-based exercise.

Implications of Overarching Conceptual Networks

The understanding of conceptual networks appears to be fundamental to the teaching and learning of difficult disciplinary conceptual content. Specifically, in biostatistics I found that the overarching sampling concepts or 'lenses' of sampling and significance are fundamental to being able to think or see like a biostatistician. This is supported by the few publications on threshold concepts in statistics and biostatistics. The findings for evidence-based practice are similar with clear demarcation of at least one over-arching, transformational concept of evidence-based practice as clinical practice. Underlying this major concept are several complex or networked concepts, including: information skills (EBP steps 1 & 2) and critical appraisal (EBP step 3). These are threshold concepts because: they are universally troublesome in terms of content and language for students, they provide transformative experiences that are irreversible; and they result in integration and understanding of other concepts. Together, this process leads to ontological change in ways of thinking, a fuller knowledge of the topic and an ability to put this integrated knowledge into practice effectively.

4.3.6 Disciplinary Perspective Effects

Unexpectedly, disciplinary differences came to the fore during participant discussion in all of the expert interviews. It seems that clinical teachers have a very different perception of EBP and biostatistics compared to academic biostatisticians (researchers/teachers), epidemiologically trained academics, medical educators and clinical research specialists. Indeed, there was a marked difference in how experts viewed the major concepts that medical students would meet in their journey through the medical curriculum towards graduation. Also, a different emphasis was placed on what is important for students to learn, and in which order. Furthermore, there were slightly different opinions on how the key concepts theoretically linked up. These were all unexpectedly strong and consistent findings and were responsible for some of the liveliest conversations during the expert interviews.

The least contentious paired expert interview was the two clinical teachers (Experts 4 & 5. They were mostly in agreement, although even here the professor with the most experience of statistical teaching and practice emphasised these elements much more than the non-statistically oriented clinical teacher, even taking a classically academic statistical perspective at times. In contrast, the postgraduate lecturer of statistical epidemiology and the clinical teacher/researcher, who knew each other (Experts 2 & 3) had the most interesting and intense discussion that continued right across their interview. This focussed on whether statisticians, epidemiologists and clinical researchers have the same shared perspective on statistics. Both participants claimed fundamental elements and concepts as belonging to a discipline (statistics or epidemiology or clinical), this being discussed and refuted, and concessions being made. An interesting exchange shown below highlights the initial tug of war about what is statistics ('stats') and what is epidemiology ('epi') and a surprising compromise where they each admitted that there was a lot of overlap and misunderstanding between their disciplinary viewpoints. In the end, both participants seem quite pleased to be entitled wear the other disciplinary 'hat' to the one they believed that they were entitled to originally:

> Expert 3: … if you can divide epi into the stats and the non-stats part there's no doubt that my PhD taught me the non-stats part. That combined with my master's, which I then put into practice in my PhD and was involved not only in my study but in others and then that gave me a good grounding, a good understanding of the epi parts of - the stats parts were more difficult.
>
> Expert 2: So, when you say stats you just – do you mean just the hypothesis testing and the competence of…?
>
> Expert 3: Yeah.
>
> Expert 2: …see, I would argue that actually the whole thing is stats, so study of design, designing studies, sampling, everything, that's all stats as well, so we're actually trained

– as statisticians we're trained in how to measure things, how to design studies and the whole gambit and people often don't recognise that as stats skills.

Expert 3: No, I accept that, from my perspective I divided it more into what I find easy and what I don't find easy and also…

Expert 2: Yeah, interesting that you've labelled the parts that you find easy as non-stats…

Expert 3: Yeah.

Expert 2: …and I would label them all as – a lot of those would be stats and taught in statistics courses.

Expert 3: Oh, goody, okay, let me change my beginning [when she introduced herself an epidemiologist], I'm a statistician!

However, despite this admittance of overlap and similarity, there were distinct differences in the terminology and expression of the troublesome concepts in this interview and the other expert interviews, along the stark disciplinary lines already mentioned: statistics, epidemiology, clinical teaching and clinical research. This was not a surprising finding as I was aware from the TCF that a disciplinary focus is central to becoming and being an academic, however, the strength of the emphasis detected in these conversations, and the implications that this could have for teaching students is significant. Biglan's research (1973, p. 202) categorised the subject matter of disciplines as focussed around three academic dimensions defined as a "single paradigm," application of the subject knowledge, and a concern with "related life systems." More recently, Becher and Trowler (2001, p. 22) posited that academia consists of bodies of knowledge and culture that create disciplinary "tribes and territories," which are by no means exclusive or totally circumscribed but inevitability can lead to division across the community. This disciplinary distinctiveness could be taken as one of the aims of higher education, but many argue that it should not be the main or only objective, or the division of silos of learning could create barriers to transdisciplinary knowledge and understanding (Barnett, 2009; Perkins, 2008). In fact, despite revealing numerous academic partitions, Becher and Trowler (2001) were keen to show that the higher education community's main strength relied on its transdisciplinarity within and across these communities.

There are numerous perspectives on this aspect of mastery and expertise that can be considered. The TCF literature appreciates the boundaries of disciplines as a necessary aspect of knowledge and ontology in academia (Entwistle, 2008), consequently economists think like economists, engineers think like engineers. Predictably then, the more statistically trained experts were more vocal in choosing statistical concepts as troublesome or threshold concepts, centred around the main concepts of sampling, hypothesis testing and statistical significance. In contrast, the epidemiologically trained, spoke of being transformed in the understanding through applied course curricula and thus they emphasised the application of concepts that were central to their own disciplinary thinking. Unsurprisingly, the clinical teachers were more focused on the transformation of students to a clinical perspective.

A further point of difference between the participants was the personal experience of transformation. Intriguingly, each expert recalled different pivotal and/ or transformational moments regarding their own gaining of understanding of statistics and these occurred in very different career circumstances and teaching environments. In general, their own early experiences of transformative learning tended to be within their own discipline and appeared to influence their perspective of what was transformational for their students. For Experts 1, 6 and 7, the sampling lens threshold was the key to understanding statistics. Expert 4 (a clinician with a statistical interest) considered the sampling "quantification of the probability of something being true" (Expert 4, Interview 1). Indeed, the epidemiology lecturer and academic clinician (who both learned statistics through public health master's degrees), concurred that their statistical revelations came through the practical application of the concepts in their master's degree, which was similar to my own statistical revelation during my Master of Public Health degree. In contrast, the paired interview with the two clinical teaching experts (Experts 4 and 5) became animated on discussion of how students gain a clinical perspective. They agreed on this as a vital learning threshold for their students, as it was a significant threshold in their own learning, with bias and validity concepts being the most memorable. This relates nicely to the Vygotskian notion that *how* the learner learns (i.e. the learning pathway that they take) shapes what they ultimately learn.

Taking this further, interesting points were raised about boundaries of disciplines, as a key threshold concept characteristic (Meyer & Land, 2005). Experts 2 and 3, discussed how we teach our students statistics and both experts wondered if it is important to delineate the discipline boundaries for them. This raised the following questions: 1) Which disciplinary perspective is most effective and useful for medical students to take to learn statistics; 2) Should we teach them more than one perspective, or is that too confusing; 3) Are students able to 'transfer' their understanding easily across these disciplines? That this issue could be of key importance to the teaching and learning of statistics and EBP was a profound and surprising finding in the interview for all three of us, and the discussion continued onwards after the interview recording ended, and meeting afterwards to consider collaborating on a paper. This discussion raised a summative question for my research: is disciplinary perspective important in the teaching of EBP or biostatistics in terms of the underlying (threshold) concepts? The data was analysed further to look for disciplinary issues regarding language, teaching approach, perspective and to see if I could determine which perspective is most effective for medical students. Also, I examined whether students realised that their teachers were presenting concepts through different disciplinary lenses and, if so, were they confused by this or were they able to 'transfer' their knowledge and skills across the different perspectives.

This additional analysis showed that it was possible to categorise key disciplinary concepts that the student meets in their learning of disciplinary areas and subjects, but it also demonstrated that there is a surprising overlap between the key transformational concept domains. Fortunately, students were able to sense a difference in the teacher's presentation, the explanations given, and their understanding of these concepts between the disciplines. This was confusing but, for mature students, quite invigorating and confirming – the element of confusion was assisting their learning by requiring further consideration. These surprising 'grey edges' of the disciplinary conceptual knowledge areas suggest that they overlap more than expected from the TCF literature. This greyness appears to be confounded and contrastingly facilitated by the use of different language and terminology, which in turn makes these similarities difficult to see for the experts, teachers, and learners. At times, the emphasis of the concept also differed. Noticeably, this was seen most often in discussion of bias. The emphasis is different for each of the discipline areas of statistics, epidemiology, and clinical practice in terms of how bias is defined, interpreted and applied. In fact, there was a detectable difference between the terminology and perspective regarding bias and validity in the sub-disciplines of biostatistics and classical statistics. In contrast, the experts with a less traditional, more health discipline-based statistical education emphasised validity in more applied terms than the experts educated using the terminology and perspective of classical statistics.

Implications for Teaching and Learning

Overall, disciplinary boundedness of threshold concepts seems to be a convincing characteristic as the research shows a detectible, maybe even a substantial difference in the disciplinary knowledge between classical statistics and its sub-discipline of biostatistics (Neumann, 2001). However, it is less plausible that the perspective around the same statistical concepts should shift between the similar disciplines of public health, epidemiology and clinical medicine. Undeniably, the data suggests that there is a strong disciplinary influence on statistical concepts teaching within different disciplines in terms of the application to and facilitation of disciplinary practice (Neumann, 2001). If terminology differences are not flagged sufficiently students may not understand slight variations and similarities or recognise their previous learning. Teaching more deliberately around these differences and explaining the need for adaptation or transfer of students' previous knowledge and terminology to the new disciplinary approach could help (Quinnell et al., 2013). Therefore, these findings around disciplinary differences and similarities could be useful for developing teaching approaches and curricular development for biostatistics and EBP.

CONCEPTUAL SYSTEMS CLARIFIED

In this chapter, I have presented the abductive findings using a Vygotskian/TCF lens that provides new and confirmatory findings regarding the major conceptual forms in EBP and medical biostatistics learning in the medical program at UNSW. From this analysis, the formation of systems or networks of concepts is confirmed to be an essential part of the learning of knowledge, the epistemological shift into disciplinary understanding and the ontological shift to practice expertise and mastery. This research suggests that conceptual networks are key to the systematisation of learning and transformational changes that occur are essential in this process. When and how this systematisation occurs during student learning will be discussed alongside the role of language in Chapter Five, and an in-depth examination of the function of the ZPD/liminal space and critical thinking skills in this learning process will be presented in Chapter Six.

CHAPTER 5: SECOND INTERSECTION – LANGUAGE AND THINKING

Inner speech "does not merely accompany a child's activity; it serves mental orientation, conscious understanding; it helps in overcoming difficulties; it is speech for oneself, intimately and usefully connected with the child's thinking."

(Vygotsky, 2012, p. 242)

The previous chapter examined how the data revealed the major troublesome and threshold concepts for EBP and medical biostatistics for the participants and detailed how these appear to inter-relate and function as disciplinary networks for more mature students and experts. This second analysis chapter focuses on the second intersection of Vygotskian theory and the Threshold Concept Framework (TCF): language and thinking. My analysis examined the language approaches used by student cases in their conceptual learning. Specifically, I examined how language is used for and by learners to assist with conceptual learning, especially when encountering troublesome threshold concepts. At the deepest level of the abductive analysis, I explored how the students' use of language in critical thinking assisted this learning. The research focus remains on the topics of EBP and medical biostatistics, but the participants also touched on relevant experiences of conceptual learning in medical science and clinical disciplines.

As the analysis continued, the language-based research perspective developed naturally from the emphasis that both Vygotskian theory and the TCF place on language and thinking. This is not an unfamiliar viewpoint; from early philosophers to modern day psychologists there is a strongly held view that there is a connection between language and thinking, including a vital association between thinking and *self-talk*. This general agreement emphasises that self-talk (known hereafter as *inner speech*) is a core element of human psychology and, furthermore, is essential for social relationships and for learning. From Vygotsky's perspective the role of language in thinking specifically emphasised the ideas of internalisation and externalisation of expert discourse as a process of mediated, self-mastery. Such processes are also discussed in TCF research (Land et al., 2014). Here also, there is acknowledgement that language is a key semiotic tool for bridging conceptual gaps and helping learners to progress through the liminal space. Furthermore, language facilitates the thinking processes that lead to the ontological transformation of the threshold concept:

> …What is being emphasised here is the inter-relatedness of the learner's identity with thinking and language. Threshold concepts lead not only to transformed thought but to a transfiguration of identity and adoption of an extended discourse. (Meyer & Land, 2005, pp. 374–5)

Vygotsky's notions of 'intelligent perception' offers the TCF another useful perspective on the transformative role of language in thinking. Within Vygotsky's scheme of development of the higher mental functions, language mediates elementary perception, transforming and developing it into a higher intellectual form as categorical or generalised perception. By integrating with language-based thinking within concepts, perception thus becomes intellectualised as "intelligent perception," as Vygotsky (1998a, p. 90) described "only with the help of the word can a child recognize things and only with the help of a concept does he come to a realistic and intelligent perception of the object."

Language is acknowledged as bothersome in TCF research, but disciplinary discourse is also seen as a key outcome of 'crossing the threshold' – the ability to think and communicate at a higher theoretical level. The assumption so far has been that language has ontological as well as epistemic consequences, "as students acquire threshold concepts, and extend their use of language in relation to these concepts, there occurs also a shift in the learner's subjectivity, a repositioning of the self" (Meyer & Land, 2005, pp. 374–5). Yet, the central role that language plays in the thinking processes of conceptual learning and threshold concepts has not been fully examined, especially in medicine. Here, the Vygotskian perspective can assist. As described by Wells (2007) language plays a vital role as a mediating tool in the dialectic interaction between disciplinary (social speech) and internal self-discourses (inner speech). Furthermore, Guerts (2018) makes a coherent argument that dialogue is a natural social interaction and hence can be considered using a communication perspective, and this includes both social (external) talk as well as dialogue from inner speech. Integrating these more recent interpretations of Vygotskian theory opens a whole new way of viewing the learning processes taking place in the liminal space.

At this stage of my research, I re-considered the social perspective within the shared discursive space of learning, including the mind of the learner. Firstly, the troublesome nature of language dominated the findings, and this is discussed initially to clarify its strong refrain within the data. Thereafter, in distinct contrast, language was revealed as the main facilitator of conceptual learning, and deeper analysis showed that it can trigger and assist transformation. Using this Vygotskian and TCF lens revealed that language is the lynchpin of teaching, learning and transformation in conceptual learning. These findings are presented below, with the conclusion that language, critical thinking and transformation are inherently interconnected, and the discursive space is more complex than previously thought. A model of these critical thinking skills and processes introduced and maintained by language-thinking is presented here and developed further in the next chapter.

5.1 LANGUAGE – TROUBLESOME BUT ESSENTIAL

Language was universally acknowledged by student cases as troublesome for their conceptual learning. As with most disciplines, medical science and clinical terminology is the cause of struggle for many novice students of medicine, nursing and allied health professions. The introduction of new disciplinary terminology has been noted to be overwhelming in its volume, intensity and strangeness across the disciplines, for instance in sciences such as Physics (Brookes & Etkina, 2007; Harrison & Serbanescu, 2017), the arts (K. Moffat & McKim, 2014), academic skills (Orsini-Jones, 2008) and within health sciences and professional training (Sturges & Maurer, 2013). A lexical analysis of a medical textbook corpus identified an astonishing 3,474 technical medical terms, plus 1,427 medical abbreviations (Hsu, 2013, p. 465). It would not be an expectation that a new medical student should know all of these terms, however, a typical student is likely to encounter many of these at some point in their training as they are used within curricular activities, learning resources and the medical research literature. Additionally, learning a new medical language is harder if you are speaking English as a foreign or second language (Crawford & Candlin, 2013), so international students have been shown to be at an added disadvantage (McLean, Murdoch-Eaton, & Shaban, 2013). As new words are often difficult to understand and technical terms can be misleading, this was accurately described by Meyer and Land as "troublesome language" as originally presented as one of the threshold concept characteristics (2003, p. 9). Importantly, further TCF research has recognised that the signification of words with specific disciplinary meanings was only part of the problem (Land et al., 2014), and, moreover, that taking on a challenging new discourse is an inherent part of the conceptualisation and transformation of the learner (Baillie et al., 2013).

5.1.1 The Student Experience

Novice students in the study found it extremely difficult to understand new concepts when taking on board new terms and definitions of the disciplinary language. Initially, they struggled with most of this new language, as they lacked even the basic understanding of these new words and meanings, causing a surprising amount of disorientation in their learning. More mature students realised that as they crossed the threshold, they had absorbed and integrated this language into their own vocabulary and effectively had navigated a transition to a higher-level of understanding as a result of this shift in their perception of the discipline and its discourse. This quote from a first-year student describes his experience during the first two months at university:

> Why do they have to rip that diagram off the textbook that's so much more complicated than we need? But it's [got] so many lines in it, it's got so many symbols, it's – you could've just used a simple analogy. And even with the technical terms, … do you really have to say 'prostaglandins'? I mean, is there any other word or any other analogy that you could use to substitute that? I mean, using all these words, especially in Foundations, is overwhelming. To understand things, you try to understand what the words mean but the point is there's just too many words. (Case 8, Interview 1)

His frustration with the terminology is almost palpable here. Other cases reflected on this problem more circumspectly. For example, a second-year student (Case 2) talked of how a single word can put students off learning. The term 'lateralisation' was used within a project option, but no one in his group understood what it meant, so they were very reluctant to choose that assessment option. However, this term intrigued Case 2, and he explained that it was this curiosity that spurred him to persuade the group to take this project option in order to learn more. His insight into the troublesome nature of terminology in medicine, might well be a sign of early maturity:

> …most of us somehow shied away from the task that has this weird word, … 'lateralisation'. So, when we [see] that word immediately everyone is okay, this is difficult, and somehow, I think that maybe people forget that the words, it's just a representational concept. The words are not difficult, the concepts are [what's] making it difficult. (Case 2, Interview 2)

In another instance, because of recent conceptual struggle, Case 2 wrote a bracketed aside in a journal entry, expressing pleasure at grasping concepts ‘as words’:

> *(note: I felt good when I understood what median means. I seem to forget what the word means over and over again despite having heard them many times in the course of my medical studies.)* (Case 2, Journal)

Interestingly, first-year students were less able to explain their trouble with terminology, but a few cited issues arising in learning experiences at the beginning of the year:

> *Simply reading through an anatomy book doesn't make sense sometimes if I am not well acquainted with the vocabulary*. (Case 1, Journal)

Many other student cases expressed confusion over the terms used and the associated inherent concepts in combination, for example the terms *sensitivity* and *specificity* (identified as threshold concepts in this study) were seen as troublesome regarding their definitions. Furthermore, the related screening and diagnostic principles of these terms were universally found to be very confusing. Student comments clearly showed that it was the combination of the new academic use of these terms together with the troublesome knowledge involved in the concepts, that made these topics hard to understand initially. All of the early program students mentioned these concepts as troublesome, explaining that they thought that they had understood it initially when first taught it but had forgotten it subsequently or found that they couldn't explain to me during the interview. As previously mentioned, only the fifth-year clinical student was satisfied that she finally fully understood sensitivity and specificity, after having seen how these principles were applied in clinical practice to real patient situations. At this point, the balance of her conceptual understanding had tipped to an irreversible state, and she experienced a pleasurable, transformed way of seeing screening and diagnostic situations. This shows once again, that conceptual knowledge and understanding is initially quite fragile and susceptible to being forgotten but can be consolidated with more concrete experiences of learning, especially where real experiences are gained within clinical practice.

Seeing the terminology as conceptual in origin often came as a revelation to students. For one second-year student (Case 2, Interview 2) this happened when he was peer teaching a first-year student one of the most confusing statistical terms, significance. He admitted that this term defied his efforts at explanation; he found that he couldn't make it "simple enough" for her to understand. Later he acknowledged that he realised that he didn't understand the concept well enough himself to teach it to her. However, it was clear to him from his perspective as a peer teacher that she didn't understand what this was "because colloquially we think the 'significance' is the importance or magnitude kind of way." He went on to explain (rather clumsily, showing his lack of sophistication with the concept) that this term in statistics is more about a "difference between the chance of it… there is the true difference." He rationalised this experience by theorising that the first-year student couldn't understand this statistical term as its meaning was complicated by all the everyday meanings of 'significance' that she already knew; he realised there was an issue with her letting go of these old meanings to take on the new one. It is noteworthy, that this second-year student (not yet even competent in statistics) recognised and was able to explain this as a double stalemate situation; he described this as the first-year student having an inability to learn this new term as she wasn't ready or able to understand the full concept and hadn't yet assimilated its associated concepts either. A first-year student summed up his beginner's insight into the phenomenon of troublesome language as he reflected on his first year at university:

> *There are many highly specific terms that you need to have in your vocabulary in order to piece them together to create a concept in your mind. This is very much about comprehending words in order to comprehend a concept*. (Case 7, Journal)

5.1.2 The Theoretical Perspective

As an expert, viewing these pre-liminal and liminal experiences using a Vygotskian perspective, I am able to theorise beyond the participants in their novice and beginner learning states. Altogether these findings on troublesome language confirm that the understanding of the new meaning of these words is a vital part of gaining a full understanding, but that this is not easily achieved. Language causes struggle in conceptual learning due to the troublesome nature of new terminology; semantic understanding of new terms is not easily assimilated, not until full ontological transformation has taken place, or as part of the transformation process. To achieve this change Vygotsky (2012) alleged that the meanings of words as signs did not remain constant for the learner but would alter as new experiences and contexts provided new meanings. This idea was later adopted by TCF researchers (e.g. Land et al., 2014) but was only touched upon by the student cases as shown above. However, Expert 1 clearly stated the importance he felt this brought to his understanding of the threshold concept of null hypothesis, saying "I mean…you know, you have to jettison your idea of what null means and re-engage with the thing, you know, having been contaminated – your thinking having been contaminated.” The colloquial saying, ‘out with the old, in with the new’ sums the lexical exchange process succinctly but ignores the strong feelings that such a step can cause as this can “provoke resistance” to learning (Green, Loertscher, Minderhout, & Lewis, 2017, p. 1404) and cause significant emotional experiences that diminish engagement with the learning (Felten, 2016).

Indeed, troublesome language was a common issue for students causing struggle, confusion and disengagement. It is not surprising that they appear to find it harder to conceptualise a concept if they don’t understand the meaning of the terms used to describe it or explain it– i.e. the signification has no meaning or has an incorrect meaning (Land et al., 2014). This backs up the TCF idea and Expert 1’s reflection above, that learners will have trouble accessing the new sign meaning of newly met terms until they have rejected the previously learned and understood sign meanings and gained a clearer understanding of what the new version means. Surprisingly, this inability to grasp the new word or term’s meaning was recognised as an almost physical feeling at times - a palpable, even visceral feeling of distress. Student cases reflected upon uncomfortable and confused feelings related to these troublesome moments. They recounted that troublesome language provoked negative reactions such as wanting to ‘give up’. On the other hand, it also invoked positive reactions such as seeking more assistance from resources and more knowledgeable people in order to understand. Students recognised this troublesome language as a problem but saw its benefit as a positive trigger for further effort in learning. They became aware of this as a learning problem but at the same time recognised it as a useful prompt for initiating a learning challenge, driven by curiosity and the determination to learn.

Even early program students were aware of the possibility of a stalemate in their learning if troublesome language was involved but expressed fear that they thought that they had ineffective skills and learning tools to deal with the issue. Several students admitted early defeat and not fully understanding these concepts yet, finding instead that they had had to resort to surface learning (despite knowing this may not be as effective for their overall learning). They confessed to using basic rote learning techniques and memory tricks when studying these troublesome concepts for exams; strategies shown to be less effective than deep learning (Entwistle, 2003; Newble & Entwistle, 1986).

Nonetheless, some students found that simply learning definitions of terms was helpful and could allow them to get some of the simpler examination questions correct. After the exams were over, students realised that learning these definitions by rote had not provided them with an in-depth meaning of the concept or concepts behind this terminology, often losing the knowledge within a few days or weeks. This aligns well with the Vygotskian understanding that clear verbal definitions are the beginning of mastery of a scientific concept, providing a "ready-made" concept on which future learning activity can be organised upon, but lacking in substance (Karpov & Bransford, 1995, p. 62). Also, this relates well with Land and colleagues' (2014) new approach encouraging conceptual learning research using linguistics and Saussurean research on the role of signification. The examination of signification in the conceptual learning process has been developed since this original idea, providing interesting insights into the effectiveness of signification for both curricular development and assisted research into affective issues in threshold concept learning (Rattray, 2014). In particular, Green, Loertscher, Minderhout and Lewis (2017) have extended the earlier ideas by examining the teaching aspects of troublesome language and the role signification has in threshold concepts.

Overall, despite the good intentions of students when meeting these language challenges of threshold concepts, the new terminology and higher-level disciplinary discourse remains a considerable barrier to effective conceptual learning for the novice and advanced beginner learners. These early findings around troublesome language described above led to further abductive analysis around the students' liminal experiences, which revealed that conceptual development links directly to this language-meaning as the initiator, performer and sustainer of transformative change.

5.2 LANGUAGE AS LEARNER-TEACHER

Further data analysis illuminated how language acts as a cognitive, conceptual learning tool assisting often troublesome transitions to higher mediated mental functions. By specifically looking at how language was used by the students (and experts) I have shown how language is in fact more than a bridge or tool for epistemological and ontological transformation of the threshold concept crossed. In stark contrast to its troublesome nature, language was directly identified by all of the student cases as an essential tool for conceptual learning. This positive characteristic was harder to find in the data and was teased out of the interview and reflective data following careful application of theory to students' reflection on their conceptual struggle points. This showed that language was undoubtedly an essential component of both standard instruction and learning activities such as lectures, tutorials, scenario groups, but on closer inspection this was a vital element of the internal, liminal conceptual learning struggle. Language dominated the troublesome and transformative learning experiences described, both as spoken instruction-learning and as a process within students' minds. Language was revealed as more than a simple tool for communication; it is an essential element of thinking for learning.

As shown previously, dialogue was a significant feature in student learning; it was mentioned by all cases. Mostly, this dialogue was between two people or more, for example in class with a teacher or tutor, or with peers in a study group. In these situations, it was commonly used for discussing, explaining and clarifying concepts. However, language was also the main element of thinking for learning, including both a less conscious and more conscious type of inner speech for self-teaching. Also, students reflected on a less conscious dialogue with self, apparently passive, that seemed to enter their heads unbidden, as could other ideas and explanations. This dialogue with self could be used actively as well as appearing to be automatic or subconscious. This self-teaching dialogue was aimed specifically towards the understanding of difficult concepts and especially those identified in this research as threshold concepts. In addition, for some student cases, private but external (i.e. voiced aloud) speech was commonly utilised as a study approach for conceptual learning.

Intriguingly, visual processing was thought to be more essential (or at least more obvious) than verbal thinking for two of the student cases, but for most cases visual processing was used as an adjunct for study and often as visually expressed written or drawn language, for example as flow diagrams. Furthermore, there were some students who spoke of comprehending difficult concepts by imagining them as three-dimensional images, or, as previously mentioned in Chapter Four, by visualising separate concepts as image objects in order to manipulate them visually in their mind to link and fit them together. Once more, emotional experiences appeared to be universally present in these liminal learning moments, creating an unexpectedly strong impact (both good and bad) on student learning processes. Interestingly, students reflected eloquently about how influential these feelings were on their learning progress. The following section details the evidence for the main findings, with section 5.2.3 detailing the abductive analysis and interpretation of the findings more deeply in terms of critical thinking skills.

5.2.1 Learning through Dialogue with Others

Dialogue for learning was a key thematic component of the language and student learning seen in the data. This included dialogue between at least two people, usually involving dialogue with an expert, teacher, tutor or other students (e.g. in a classroom situation), or with one or more peers in a class groupwork situation or in informal study groups. Indeed, peer-learning and peer-teaching were strong themes within the student case data. Students accepted that teaching others was a learning tool, embracing these opportunities to study actively together and tutor whenever it was possible. The students recognised this teaching effect as a powerful positive effect on their conceptual understanding and also their confidence. This appeared to work just as well when they were teaching themselves, even when they prepared to teach others, or if they pretended to teach others. When the non-case data was examined, the experts echoed students' impressions that teaching others involves active learning, discussion and argument in order to present the concepts more clearly, and that this provokes further learning. This corresponds well with local research. A structural vertical integration of the first two years of the medicine program at UNSW was found by Scicluna and colleagues (2015, p. 7) to have encouraged active peer learning that resulted in deeper learning and also development of "leadership qualities" within the student team groups. Therefore, it was unanticipated in my data that some students were not very trusting of the quality of learning resulting from peer study and tended to seek the expert or a more learned peer whenever feasible. This second-year student mentioned that he would prefer to ask *"an expert on the topic to clarify my understanding of the concepts, thus mitigating my anxiety on whether my understanding is faulty or not*. (Case 2, Journal). With a later nod in deference to the teachers' expertise in navigating the conceptual terrain, he explained:

> I think maybe we can see that the teachers possess a more elaborate, better map, so their maps correspond more to the territories, where for someone like me, maybe the map is blank, or maybe there are a lot of scribbles. (Case 2, Interview 2)

However, more advanced students were seen as useful teachers: "I've talked to one or two of my friends – and they might have done a year of med science last year… and they've been able to explain it and I find that extremely helpful" (Case 7, Interview 1).

Sometimes, though it was just the talking that was helpful, so the knowledge of the others in the dialogue was not as important, as being able to talk about it:

> I mean, I don't feel that it's they're very good teachers…– I don't know, maybe that's the type of learner I am, just by talking to others --- but I do find that very helpful as well, the peer teaching and then in combination with having my own notes, I think. (Case 7, Interview 1)

Then, later on in the year, this same first-year student felt capable of taking on the role of teacher for others regarding sensitivity and specificity, and that this was a strong motivator to re-learn the topic, in order to teach it well:

> … I also had to go to the next level, like thinking about how we would teach it. And I think once you get to that stage … it's a given that you know what you're talking about. Now you're thinking about the best way to teach it. So, I think [teaching] is a powerful mechanism – forcing yourself to learn. (Case 7, Interview 2)

Similarly, peer discussion can create a conceptual learning process. Confused by the contradiction between the prescribed texts and a lecture on a key physiological concept, one student sought a peer to discuss these theoretical issues with them, and through this discussion he created a new understanding (Case 2, Interview 1). When asked what was happening in his mind for this concept to become clearer, he said "something is happening. I'm trying to piece the puzzle or something." Then he offered that if that didn't work "the next step would be to ask someone who is an expert on this" (Case 2, Interview 1). However, peer teaching for this student was once again useful when he was less certain of a concept and actively sought to create a more confrontational interchange with a peer to stimulate his thinking:

> I guess I'm only for peer teaching if it's a concept that I know that I can't understand myself, and when I talk to others it's more argumentative, in a way. So, 'this is what I think', and the person needs to give me a rebuttal. It's like I want people to polish my thoughts and try to prove it wrong. (Case 2, Interview 1)

Later in the year this same student reiterated this need to meet conceptual challenges head on, using dialogue with others or with himself, with the purpose of identifying what he did and did not understand. He wrote about being in a "*knowledge bubble in which I am stuck believing that I have the correct understanding of a topic which in reality is incorrect*" (Case 2, Journal). This "knowledge bubble" is a clear pointer to a TCF liminal space experience, being a learning place where he was unclear and uncertain in his understanding. He recognised the need to have "moments that help me spot any potential knowledge bubbles I am in." He went on to state that the act of dialogue on a topic was one tool to achieve this. As with other students, some of this dialogue was to self, within their mind, and was often used to check on their level and depth of understanding and apply further critical thinking learning processes, especially at points of liminality when they were uncertain, unsure or met with troublesome knowledge or language. This is examined later in this chapter.

Language in the Learner-Teacher Relationship

These findings about dialogue challenge recent research on conceptual learning that has concentrated either on the student-learner or the expert-teacher. I have argued in previous chapters that these focussed approaches have minimised the effective examination of conceptual learning as a holistic process. In Vygotsky's theory of the Zone of Proximal Development (ZPD), the process of learning is a collaborative process, especially at the point of conceptual difficulty. Hence, there is a key role of the adult (or more knowledgeable peer) as a learning collaborator for cognitive development, but Vygotsky also privileges the inner learning process.

Further analysis was undertaken to examine the role of the other in this process. To assist, Laurillard's conversational framework (2002, p. 87) was applied to my data, across the whole dataset around the conceptual learning moments. This revealed the learner-teacher relationship as an essential element of the learning process; students emphasised the role of the lecturer in learning activities and as a trusted guide to their disciplinary learning. However, the analysis also revealed how students frequently access and use library and online learning resources from their course and also from other sources (such as YouTube). They use these resources as reference for further study on their own and with others, especially when they are stuck or struggling with conceptual understanding or troublesome language. This was not unexpected as the medicine program emphasises and encourages self-directed learning approaches and personal study time (McNeil et al., 2012). Interestingly, the analysis went on to reveal that students considered that the reflective dialogue elements of the learning process were just as essential to their learning as instructor or peer dialogue. So, there was evidence to support students moving through all the student steps of the conversational framework. With reference to Figure 3.2, theory and ideas are leading to student conceptions, followed by re-iteration of the development of understanding of these alongside the students' self-reflection and actions, with adaptation of this as their understanding of the theory and goals developed. However, their use of dialogue with peers and interaction with multiple resources, suggests that this dialogue or conversation is extended to become a 'collective ZPD' in the modern curriculum. A modification of this framework according to these initial findings into this dialogic process would suggest that the student's conception should directly interact (via re-description, new theories and ideas, reflection and action) with peers (i.e. teaching each other), as well as through the official teacher.

In addition, there was a recognition by students that the learning setting was complex. The liminal space is entered or the ZPD is initiated during class time during interaction of teacher and learner, but the data shows clearly that there is considerable struggle and conceptual loss and gain by the learner outside of these face-to-face moments. My student cases reflected mostly on the manipulation of these conceptual puzzles outside of class; apparently, they are struggling to learn the concept mostly on their own. So, the learning process can begin before the class conversational interactions if the student meets the concept prior, can continue on and off during the class interaction, and usually continues long after the actual physical conversation learning interaction takes place. The learner revisits the concept and grapples again and again with the learning, seeking support from various other resources during this time and using their inner conceptualisation processes for this learning. These factors of time and place are acknowledged but not well elaborated by the TCF, Laurillard's conversational framework or the Vygotskian theory of conceptual learning. Regarding the ZPD, it is noted that it is presented rather simply as a zone where instructor and learner interact to develop higher mental functions, without clear frameworks of the instruction or processes that can enable the learning therein (Zaretskii, 2009). Overall, these initial findings from the data revealed key information about language as dialogue in the liminal space experience but showed that there was more to learn. Further analysis was undertaken to examine more clearly how these inner experiences (such as inner speech) enable conceptual learning.

5.2.2 Inner Dialogue for Conceptual Learning

On applying the conversational model, whilst being mindful of the Vygotskian and TCF perspectives, the data revealed an astonishing level of awareness amongst all eight student cases of their use of inner speech in different types of self-dialogue and monologue for studying and conceptual learning. Vygotsky (2012, p. 239) stated that "inner speech is speech for oneself; external speech is for others." However, he saw inner speech as different to external speech, both in format and purpose; development of inner speech in a child marks the "birth of a new speech form" (Vygotsky, 2012, p. 244). Inner speech and "written speech" are speech for oneself that he classified as "monologue" compared to external speech which is mostly social dialogue (Vygotsky, 2012, p. 254). However, the student case participants were forthright in declaring that their use of inner speech was often experienced as dialogue, as this example from a first-year student demonstrates:

> Yeah. I definitely think that a voice is always there or there's always questions. … – but you need to be able to realise it. Suppose I tell you about a new concept, the first thing you're going to think about is: 'What is this?' And that's your inner voice – that's a question: 'Well, what is this?' (Case 6, Interview 2)

He was clear that his inner voice was active in interrogating his understanding of concepts. Other students also described their inner speech as questioning or as active dialogue and considered this as either self-teaching, active self-argument, or as taking part in a more formalised self-discussion. This seems much more complex than the simple self-monologue that Vygotsky was contemplating.

The simplest form of this self-dialogue was a straightforward self-questioning, often with an active questioner role voiced by self. This seemed to be employed quite often and instinctively to work out how much the student already knew about a new concept or concepts. Students were open that they felt this was a normal, useful, everyday learning process:

> I guess being able to talk to yourself is a really important part of being able to do that because, unless you keep on talking to yourself while you are being exposed to new information and you have this whole lot of new stuff coming into your brain, … - so, I don't think you would be able to relate to that new knowledge because basically, that new knowledge that you are being exposed to, the absorption of that new knowledge is essentially depending on how good your previous concepts are. (Case 1, Interview 2)

This importance of reflecting using self-talk to recognise new and old knowledge as concepts is worth touching on here but is analysed fully later on. This student's reflection relates well to Vygotsky's idea of current understanding of spontaneous, everyday concepts building and reforming with new academic concepts via semiotic mediation and psychological tools in an inner thinking process to create consolidated, internalised concepts (Vygotsky, 2012). This also relates well to the fundamental TCF notion that previous concepts are integrated and remodeled as part of the transformative threshold process (Land et al., 2005; Meyer & Land, 2005). Laurillard's conversational framework (2002, p. 87) recognises learner reflection as a key element of the conversational learning process. To further examine the process, I referred to McCulloch and Field (2014, p. 3), who eloquently state how they see this working for first-year higher education students:

> the external 'real relations' are expressed to the student through language, and the student's processes of speaking to oneself that are internal reflection and argumentation are constructed, and gradually modified, until personal language is 'shaped' into the language of the discipline.

This emphasis on the need for self-reflection on their understanding and even moments of self-argument were clearly shown within the data, with a surprising importance given to the active inner dialogue element of this process. For instance, for some of the student cases self-dialogue involved a formal characterisation of inner voices or role-playing of more than one voice and character involved in a teaching-style dialogue. The complexity of this inner voice characterisation or active role-playing was an unexpected element of a more formalised self-teaching that extended beyond the basic self-reflection on understanding as seen in Laurillard's framework (2002). Three of the cases identified different, distinct characters in their self-teaching, as unvoiced inner dialogue and also voiced as private speech. These students recognised these internal voices as their own voice (so not a voice from 'outside' themselves) nonetheless some of these voices had sophisticated traits and roles. The most advanced example of this was from Case 2, who recognised active role-playing. He had just mentioned that he was aware of a "devil's advocate," argumentative voice that questioned and challenged his understanding. On being asked if he heard other voices:

> I know that it's not just the critical devil's advocate, there is another voice, and this is more the kind of guy that - the kind of person that you bounce your ideas, and he somehow supports you, yeah. It's more like he tries to clarify the things that, yeah.

Asked to expand on the role the devil's advocate and the 'clarifier' voices had in his learning, he said:

> They're always there. I need both because I need the sceptic, the critical part of me to make sure that my understanding - …I heard this analogy before, like you're trying to match the map with the territory, so I want to make sure what I understand is really what is the thing that I need to understand, so I don't want to think that, okay, I understand this, but in actuality I don't understand it, so *that one* tells me to do that. [emphasis added]

Later on, he explained this questioner/sceptic/critical character further:

he's the kind of person that tries to go deeper into a subject. ‘What if this is the case?’ ‘What if this is - consider this alternative?’ ‘How you respond?’ ‘How would this principle apply to that?’ (Case 2, Interview 2)

A fascinating element of his experience is that he said he sometimes felt as if he was “sitting in between” two voices, as himself, listening in, or being asked or even demanded these questions by the two different voices. This appears to be a method of self-detachment from the content, in order to have a more objective view in the learning dialogue. The student realised this process had developed earlier during later school years; he had been aware of it for some time and was comfortable with it. For this student, the external voiced private thinking that is perceived as a developmental stage in early childhood in Vygotskian terms (2012) has developed into a sophisticated inner speech tool for learning.

Examining this practice further within the data, I found that several students (including the student above) reflected that this interrogative inner voice was even more effective when spoken aloud as external speech. They found that this had the benefit of a more active mode of learning. Two students often talked aloud to themselves for learning purposes, and both of these students expressed the certainty that talking out loud was more effective, especially when learning difficult concepts. For example, the inner speech handling of concepts was less clear for the same student as above (Case 2), who found that the physical act of talking was more obviously a teaching mode:

…my mouth is like the teacher trying to talk, and then I am processing that... I mean, I talk [out loud] in a more explanatory manner, but in my head it’s just this - a lot of statements on concept, there’s no sense of effort to try to explain. I guess it’s a different dialogue, compared to physically talking. (Case 2, Interview 1)

More specifically for this student, it seems as if the physical action of talking out aloud promotes learning processes that help the concepts to stick in his mind more clearly:

I guess when I try to talk in my mind it’s different, compared to just talking aloud. When I try to talk aloud, I’m not sure, somehow it cements the concept, compared to just in my mind. So, in my mind it’s a bit more…it’s not that clear, compared to what I can say. (Case 2, Interview 1)

Another student explained that a similar experience with speaking aloud enabled a more distinct understanding to develop:

I suppose, it’s so fluid, that’s the thing. If I verbalise it [spoken aloud], it’s more concrete. The thoughts are more set. If it just in my head it’s – nothing is fluid, nothing much really happens. It’s not – I think it’s a really hard thing where there's these things floating around. I’m not actually doing anything. It’s like, I think, is that real? Is that true? Is that absolute truth or is it just one side of things that…? (Case 8, Interview 1)

A different student had an alternative interpretation of these learning experiences, saying that talking aloud to himself, “forces” him to think that he’s “learning more” and goes on to try to explain how this is happening:

> It’s almost as if someone else is teaching me, I think – I guess, instead of I’m teaching myself. I don’t know if I’m hearing it, it’s another part of my brain … – another part of learning activates, which is hearing yourself, rather than just hearing … - it’s out of your mind. (Case 6, Interview 2)

Case 6 seemed to think that the *hearing* part (“out of your mind”) is essential to the process; that the action of verbalising the teaching externally forces a more active learning process and that this is helpful. To understand how this process might be working, further theory was applied to this interesting data.

Current research suggests that inner speech is mostly fast, subconscious and compressed (Alderson-Day & Fernyhough, 2015). Hence, it can go by unnoticed, be too easily created and subconsciously assumed, or just missed, left unacknowledged. For some students, the process of creating their self-speech physically, voicing it out aloud, could be a more active process that is less reliant on the compressed, fast inner speech-thought. In this voiced self-speech, the slower, less compressed (but not totally decompressed) dialogue may stimulate deeper thinking more, giving the working memory a boost and hence enabling further application of critical thinking to the problem. Furthermore, from the data, I appreciated that actively talking to self, as if teaching – even in the student’s mind (not voiced) happens and is accepted as a very useful and common learning process. This suggests that this is an internal self-dialogue which might be less compressed speech, and is more actively created, and hence stimulates and applies useful thinking to the problem in a similar way to voiced self-speech. This theory was corroborated during the second interview with Case 7, who was talking about how he needed to concentrate and be quiet. “I will take the headphones off and really kind of think about it” in order to try to focus. Then, he spontaneously offered this:

> It’s almost as if you are teaching sometimes. You’re saying, okay, so if this happens and this will happen and this has happened, it’s all that kind of thing. But I think that – probably internal monologue is quite powerful. (Case 7, Interview 2)

He saw this process as a monologue but recognises that he is actively teaching himself, and that this leads to more learning. However, for Case 7 this was his own voice, not characterised or taking any specific role: "…often, it's your own voice that's kind of explaining to yourself."

So, the students' reflections here reveal an interesting pattern of learning behaviour that seems to be a magnification of the student role in Laurillard's conversational framework (2002), to replace the role of the teacher with the self as teacher through the remarkable power of inner speech. Previous research on the quality of inner speech and sophistication compared to social speech is contradictory and mostly theoretical. Current research suggests that inner speech is sometimes but not always different in the quality to external speech (Fernyhough, 2016). There remain differences in opinion about this, but mostly there is agreement that with introspection we realise that we are thinking in inner speech although we are not always conscious of it (Vicente & Martínez Manrique, 2011) and that the role of this inner speech is multiple, with the main role being the communicator in the mind, and also between the mind and the social, a "broadcaster of thoughts" (Vicente & Martínez Manrique, 2011, p. 212). Also, it seems to have various cognitive functions such as self-regulation, reasoning, memory, planning, and for internal reflection, motivation and decision-making (Frankish, 2018). Furthermore, Carruthers (2015b, p. 33) explains the idea of an "imagined audience" that he assumes must be created when we talk to ourselves with the purpose of rehearsing a speech or idea. My data indicates that in theory, this imagined audience could be extended to an imagined conversation or even a detailed argument with self, with the main purpose of reasoning for conceptual learning. This could also help to explain the student learners above who have created adversarial interlocutors with which to spar regarding the conceptual meaning of troublesome language and explanations of difficult concepts.

It is important to note that students also used inner dialogue for active memorisation of lecture content, in re-*hearing* the content in their minds, also in active re-listening by re-playing audio-recordings of lectures or using video material for learning (e.g. YouTube resources), as well as creating teacher-styled question-and-answer dialogue with inner and private speech. For one student he was asked a question by a peer that provoked a direct remembrance of a quote from a teacher: "…sometimes you just remember something that the lecturer had specifically said … and you can just recall that" (Case 7, Interview 2). This student recalled what the lecturer said as if it was literally heard in his mind, as the lecturer's voice. Other students reflected on the way that they listened actively to their own questioning dialogue to interrogate more closely their understanding of a concept. A second-year student recorded this actual self-questioning process in this extract transcribed from his audio journal:

> *Looking back at today's lecture… on risk… and I'm thinking my understanding of sensitivity and specificity…specifically because I can't really distinguish ...nah!... I can't... get away from this idea that positive and negative - that's only two outcomes - an extreme test should be only two outcomes? ... How can it be two?? Sensitivity and specificity? We'll see…* (Case 2, Audio journal entry, transcription)

This appears as if he was speaking his learning as a 'stream of consciousness' with an active questioning process rolling along in his mind. In fact, not all the student's questions or responses to self are recorded; initially there are answers to unspoken questions, then a list of questions with pauses where answers might be. This suggests an inner dialogue that doesn't completely convert to external speech (as captured by the journal audio recording). However, this extract demonstrates clearly the way that his inner voice was querying his understanding of this troublesome concept. This form of speech appears very similar to the early private (external) speech of young children, the step by step thoughts, spoken aloud to self (often when others are present) that comes before private speech is internalised at a later age (Vygotsky, 2012). This is a form of socially dependent speech for children (as less often used in the absence of others) but being employed by an adult learner to stimulate self-explanation and clarifying understanding (Fernyhough, 2016).

To understand this further, the idea of *inner hearing* was explored. Hurlburt, Heavey and Kelsey (2013) elegantly describe how hearing yourself thinking (or other inner voices) is termed inner hearing. They make a clear distinction between inner hearing of an inner utterance or something imagined (like a refrain of music), and the experience of hearing something that exists in reality in the external environment. They also point out the subtle difference between inner speech and inner hearing that people find hard to clarify in their own experience. To explain this, consider an updated version of Hurlburt and colleagues' analogic description of a tape recorder (2013, p. 1485). If you record your voice with an audio recorder on your phone, when you are speaking into the audio recorder, that is equivalent to inner speech; you are aware that you are speaking actively. In contrast, when you play back your recording from the audio file, you are listening to your voice; this is a heard experience and the equivalent to this in your mind is inner hearing. It should be noted that, as the students are aware that these voices are their own, they did not experience them as being from outside their self. Auditory hallucinations are voices that are not experienced as if from the self. This type of voice-hearing is a not uncommon experience in certain mental disorders such as psychoses and schizophrenia, although they may have a similar origin to the self-talk, the brain is processing and perceiving them as external to self (Fernyhough, 2016).

Listening, internally for inner speech and for private speech is not so different to that experienced by listening to others' speech, as mentioned above. Research around inner speech and the learning listening mode occurring in this process (inner hearing) has demonstrated why this is experienced by the person as a dialogue despite it being self-speech and there being no other person involved in reality. For this inner dialogue effect to happen, it is thought necessary for the so-called executive functions of the brain to be engaged alongside the social cognitive systems so that they work together as agents for the dialogue and can assist in accessing long-term memory for learning (Alderson-Day & Fernyhough, 2015). Initiating the other parts of the brain when using verbal thinking recruits more working memory, which in turn allows more time and therefore thought to be spent on the conceptual learning, resulting in more positive outcomes (Alderson-Day & Fernyhough, 2015). Early neuroimaging research suggests that the theory-of-mind regions in the brain are also activated by this process, with the effect that the self can speak to itself as if to others (Alderson-Day & Fernyhough, 2015). As mentioned above, research suggests that inner hearing appears to be substantially different to an active listening mode which is learning by listening and re-listening to actual auditory input. Together, these current theories suggest that inner dialogue (with or without character voices) stimulates other areas of the brain and if spoken out aloud as well, activates and utilises even further areas of the brain; a phenomenon that is only now being investigated using detailed brain scanning techniques (Alderson-Day & Fernyhough, 2015).

In my data I was impressed by the students' ability to innately understand their inner workings without any explanation from me. They were clear that they were speaking in their mind as inner speech and that they were actively using inner hearing for conceptual learning (as other character voices or more often their own voice being used to speak at or to them). These common more conversational experiences for learning could be called *inner talking* or even *inner social speech*. Furthermore, these students are using an *inner self-teaching* process for making meaning.

5.2.3 Inner Speech for Motivation

Writing about working memory, Carruthers (2015a, p. 17) makes an obvious statement that "not all inner speech has an imagined audience." By this he is referring to inner speech as inner commentary and for mental reasoning. This non-dialogue inner speech was also noted by the student cases and was often experienced as a critical and/or a motivator voice. This type of inner speech (as character voices or as self-speech) had a more indirect effect on their learning. The voices were recognised as a part of a critical self, utilised consciously, subconsciously, and unconsciously, even automatically for self-reflection with the aim of supporting self-direction and self-regulation. There is no doubt that this motivational process has a role in promoting self-efficacy as well. The data analysis uncovered student recognition of episodes of strong self-discipline and criticism as a form of self-evaluation. There were moments of self-admonishment described in the case journals, but also the opposite. Positive self-encouragement, praise and reassurance were recognised by students as well. One second-year student was very good at recording his personal criticisms in his journals, for example when he had struggled for a while to understand the threshold concept of degrees of freedom, he noticed that he was thinking (and actually had an image in his mind) of his friend, who he realised would understand this much quicker, and he wrote that this:

> *induces self-defeating thoughts such as:*
>
> *Just give up, W. You have better things to do.* (Case 2, Journal 'aside')

He continued providing excellent material on his self-criticisms and feelings, including one intense reflective moment in an audio tape:

> *One thing I realised about myself is I rarely have a 'I got it' moment during the initial learning session; I tend to ruminate, get frustrated, sometimes giving up, and suddenly I got it.* (Case 2, Audio journal excerpt)

In a later audio-file, there is critical analysis of the learning process that he's just recorded:

> *I don't think I am confident about my understanding as I am the same way I am confident that… I need air to breathe, which means that there's these niggling feelings I may had [sic], that maybe I could be wrong, maybe I haven't tried enough, and tried enough to understand this, but… it is getting better…* (Case 2, Audio journal excerpt)

An even later written reflection reveals an open ability to comment on his own grasp of hypothesis testing, and was slightly more reassuring than the self-criticisms in previous reflective journal entries: "*To be honest, my grasp of the topic is still shaky but somehow, I am confident I am on the right track. Hopefully, I am correct in my confidence"* (Case

2, Journal entry). An example of inner speech that seemed to be directed more at encouragement, was provided by the fifth-year student during her second interview:

> …if I get something done or if I manage to understand something that I found difficult, like something clicks, then I'm very, I think, encouraging of myself. Like I have those, 'Good on you,' yeah, that kind of stuff. (Case 3, Interview 2)

At times these inner non-dialogic processes appear to facilitate other verbal (active and passive) thinking processes using inner speech. These moments seem to act as key trigger points for deeper learning and application of critical thinking that could go on to aid understanding of a threshold concept. A further point is that these can be self-initiated (or self-inflicted) emotional trigger points for transition to other learning states. The self appears to use inner verbal nudges to initiate movement into a type of thinking state for learning. For example, students reflected on admonishing themselves to 'buckle down' and work harder and be more focussed, and this had exactly that effect. This was the subject of the next round of analysis.

Altogether, these student experiences suggest that language as inner speech is playing an important role in self-efficacy, self-direction and reflective practice for these students. These attributes are key generic skills that are explicitly and implicitly set out in the graduate capabilities in our medical program (McNeil et al., 2012). The curriculum actively encourages student development of these skills, but it is impossible to tell if this has an effect on their inner thoughts. Self-efficacy as we think of it, was originated by Bandura (1977) as an integrative theoretical psychological framework for use in therapeutic practice. It is commonly accepted as an important factor of human agency. Simply put, the confident are seen to be more likely to succeed than the less confident. This approach has been used successfully in academic education (Metcalf & Wiener, 2018) to promote behaviours that stimulate confidence and motivation and thus improve performance, outputs and outcomes. Within medicine, educational development and research on self-efficacy is a growing trend (White, Gruppen, & Fantone, 2013), playing a key role in curricula and expected graduate competencies (Klassen & Klassen, 2018). My research suggests an interesting aspect of self-efficacy arising from inner speech that warrants further investigation in medical education.

5.2.4 Inner Speech and Thinking State

Surprisingly, students often spoke of the state of their thinking. It appears that students seek these states, often pushed into them by emotional triggers, or they can drop into them automatically. Occasionally there were moments when a student decided it is necessary and actively created the right environment for a specific learning task or process. Inner speech was noticed by students as a trigger or facilitator of other verbal, more passive thinking processes such as a type of thinking as ‘stream of consciousness’ or ‘flow’. The fifth-year student found these moments of learning “in the flow” enjoyable, but thought that this was not actually a conscious state:

> I really enjoy maths, especially that, kind of, going from step to step. You have some information and you need to get to a solution and you’re just, kind of, in another mind set, and you’re, kind of, exploring different ideas and paths and ways of putting information together so quickly that you’re not even aware of it and then you just, kind of, move from step to step and then you’re at the answer. Yeah, I really enjoy that. But I think it just happens – I’m looking at all these different ways of putting that information together … and … I wasn’t really consciously thinking about it. (Case 3, Interview 2)

This state of flow sounds similar to happiness state of *flow* as introduced by Mihály Csíkszentmihályi in 1975 and defined as the “psychological state in which the person feels simultaneously cognitively efficient, motivated, and happy” (Moneta & Csikszentmihalyi, 1996, p. 277). There is accumulating research suggesting that being in the flow can enhance performance, because a major component of flow is concentration and merging of “action and awareness” (Landhäußer & Keller, 2012, pp. 67–68). However, it should also become an “autotelic experience,” intrinsically motivating and engaging, enjoyable with the impact of increasing one’s sense of control over the activity, reducing one’s self-consciousness and even transforming the experience of time (Landhäußer & Keller, 2012, pp. 68–69).

A good example of a similar flow state was provided by the Case 2 audio file transcript. This is interesting as it shows that this second-year student was completely wrapped up in his own experience, speaking to himself for learning, rather than thinking of conveying his reflection on the learning to me as the prospective listener of his reflective submission (researcher). This excerpt shows a very focussed way of reflective thinking with self-questioning of specific topics, that actively challenged his conceptual understanding. Interestingly, Case 3 described the very opposite feeling to this subconscious sense of flow, experienced when she gets stuck conceptually. When this happens, it appears that she is jolted so far from her learning flow state that she has to rely on others to take on her learning for her, posting up her questions to peers and waiting for assistance.

In addition, several students mentioned needing calm or quiet to learn under certain circumstances (e.g. if 'really thinking hard'). For example, reading silently but with meaning needs quiet with the proviso that this form of reading requires active application of critical thinking elements. Calm essentially seems to allow good or clearer thinking. "I don't know what it is about that sense of calm that you're in or that feeling that we've already learnt this, that just helps you locate what it is that you're looking for" (Case 6, Interview 1). This suggests that calm assists focussed thinking.

Focussed thinking was also deemed necessary at times by students. Focusing on the learning, not the feelings of confusion or disappointment, was a common theme:

> I'm getting a bit better, because right now I'm a bit more - I try to focus more on the process of reasoning themselves, not the confusions. (Case 2, Interview 2)

Similarly, Case 7 was clear that for him the focus was key to finding a good environment for "hard concepts" to be understood through active thinking processes, and needing quiet for this full focus, as if he needs to be able to listen to himself:

> Yeah, I often find you do you have to be very focussed and … sometimes, I listen to music when I'm studying because … I guess it may not require like 100 per cent mental capacity and focus on what I'm doing... But if you're learning a particularly hard concept – I will take the headphones off and really kind of think about it. (Case 7, Interview 2)

Through concentration this student says that he can focus, knowing that concentrating was important to allow him to follow his internal voice as it took him through conceptual processes. This need for focussed thinking for a concerted learning effort was confirmed by Expert 1 who explained that he only really learned key statistical concepts when he was able to focus. This only happened when given the right 'hook' that worked for him, and also being at a more mature stage of learning: "Maybe you have fewer distractions, maybe you can turn your mind with more discipline to something that's challenging" (Expert 1, Interview). Thus, as is often the case, maturity and more time for thinking enable that final transformational learning moment.

In contrast to flow and focussed thinking states, I was surprised to find that some students actively seek to let their mind wander as a studying technique. Diffuse thinking was described by one student as creating an opportunity for understanding as it clears his mind; he experienced a mind less focussed or cluttered by other ideas or concepts. Case 6 explained that he had been looking out for learning tips and discovered this as an approach to improve learning. He used a complicated and slightly woolly analogy he had heard of the brain's thoughts as a pinball game to explain how the diffuse thinking works. I've interpreted his explanation further as I think this is helpful. In terms of the analogy with the pinball machine: when the pinball (initial idea/thought) is kept up in one top corner of the pinball machine (mind/brain), pinging to and fro' on the machine's buttons and levers, scoring OK but being limited up in the corner to what is available there regarding possible scores (ideas). This is focussed thinking. In contrast, in diffuse thinking, the pinball (initial idea/thought) moves more freely around the whole machine (mind) to score more varied, different score points for the game (new understanding/experiences, conceptual learning) and connecting more widely across the machine (mind). Hence the pinball (initial thought/idea) can create more different, interesting scores (more conceptual links) by going around the whole machine (in diffuse thinking).

This student was adamant that this method was working for him, and interestingly he was clear that language was central to this process. Specifically, he talked of how analogies helped to create this type of thinking approach by freeing up the focus. He thought that this thinking widened his conceptual thinking to a parallel, more creative conceptual learning that allowed less focussed, more diffuse thinking, and therefore allowed him to grasp the concept more easily. However, there was some contradiction for Case 8 in his description of states of thinking that flowed, others when there was nothingness (which might have been diffuse thinking). "Nothing is really happening. It's like in the meditative state where you'll think about nothing" (Interview 2). This contrasted with other times (that he seemed to prefer as more useful for "proper learning") when his thinking was more active – for example, when "I talk or write or read something that's stimulating I'm actually actively thinking about these things and that will be stimulated then" (Interview 1). He mentioned that to get away from his thoughts "floating around" he thinks aloud to make his thoughts "more set."

So, diffuse thinking seems to be another different way of thinking, related to mind-wandering, and can inspire creative or innovative thinking. It has been shown to be initiated by an undemanding task (Baird et al., 2012) and has complex links to theories of consciousness and meta-cognition (Bastian et al., 2017). It seems that diffuse thinking stops the brain focusing in one place so that the mind wanders, intentionally or unintentionally, creating more possibilities for conceptual linkage and parallel ideas, but less focussed attention for matters at hand (Seli, Risko, & Smilek, 2016). So, it can be useful for innovation and creativity but can also be an inhibitor of learning if attention is required for an activity, for example, if the mind wanders in a lecture poor knowledge retention results (Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012).

In summary, the four formats of thinking that were identified from the data (flow, focussed, calm, and diffuse) appear to overlap a little but were distinct enough to be categorised as separate. They were used concurrently and sequentially in the examples given by students. This suggests that ordinary dialogue for learning, inner dialogue, external speech, and analogy can have very different effects on the thinking (and vice versa) for different students. It appears that a change of thinking state can just happen, or can be initiated by different triggers, including troublesome language and conceptual struggle. Also, a thinking state can be summoned by the learner and actively applied in different situations and different purposes. Transitioning between these thinking states appears to be both automatic and more conscious; they can be passive or more active experiences.

Three major analysis questions arose from these findings: 1) Is diffuse thinking enabled by analogy, as the analogy is something you know so it makes thoughts easier? (i.e. spontaneous concepts or previously assimilated scientific concepts); 2) Does external speech activate other brain areas via feedback loops to allow deeper thinking?; and 3) Is there a dormant developmental learning process awakened in learning during these learning states that initiates an active pathway for switching on working memory and critical thinking for problem-solving and evaluation? Unfortunately, these questions were not answerable with this study's data, my research approach and methodology. However, my research demonstrates that these thinking states are being used by students to create meaning and to facilitate activation of deeper learning and to encourage the application of critical thinking.

5.2.5 The Learner-Teacher

As shown, language is often a barrier to student conceptual learning, yet at the same time it is essential to its success. In looking at the transformational conceptual learning process it was clear that learning disciplinary language at medical school is tricky but can be used and assimilated by students for understanding and integrating the key conceptual elements within and across the medical disciplines and clinical practice. At the same time, learning acts through dialogue with the instructor (academic or peer or self), and via multiple learning sources in multiple formats. I have demonstrated how language as inner and private speech is essential to these students as a tool for conceptual learning, connecting with inner visual imaging and being influenced positively and negatively by emotional experiences. Furthermore, there is evidence from my data to support previous research showing that semiotic mediation is used subconsciously and consciously by students throughout their conceptual learning. Finally, there was a suggestion at this stage of the analysis that language is the key mediator to stimulate the necessary critical thinking to achieve conceptual understanding. Language creates and stimulates the learning, it acts as a learner-teacher in external conversations, dialogues and private speech, and within the mind as inner speech. At the same time, language can cause an opposite effect, inhibiting learning by being troublesome or via demotivating self-criticism that can leave the learner stranded, confused or dejected. These findings confirm language as central to learning and inner speech as a major part of the conversational interactions that facilitate learning (as depicted in Figure 5.1). The next section reports on deeper analysis of the data to isolate how critical thinking is assisted by language in the liminal space.

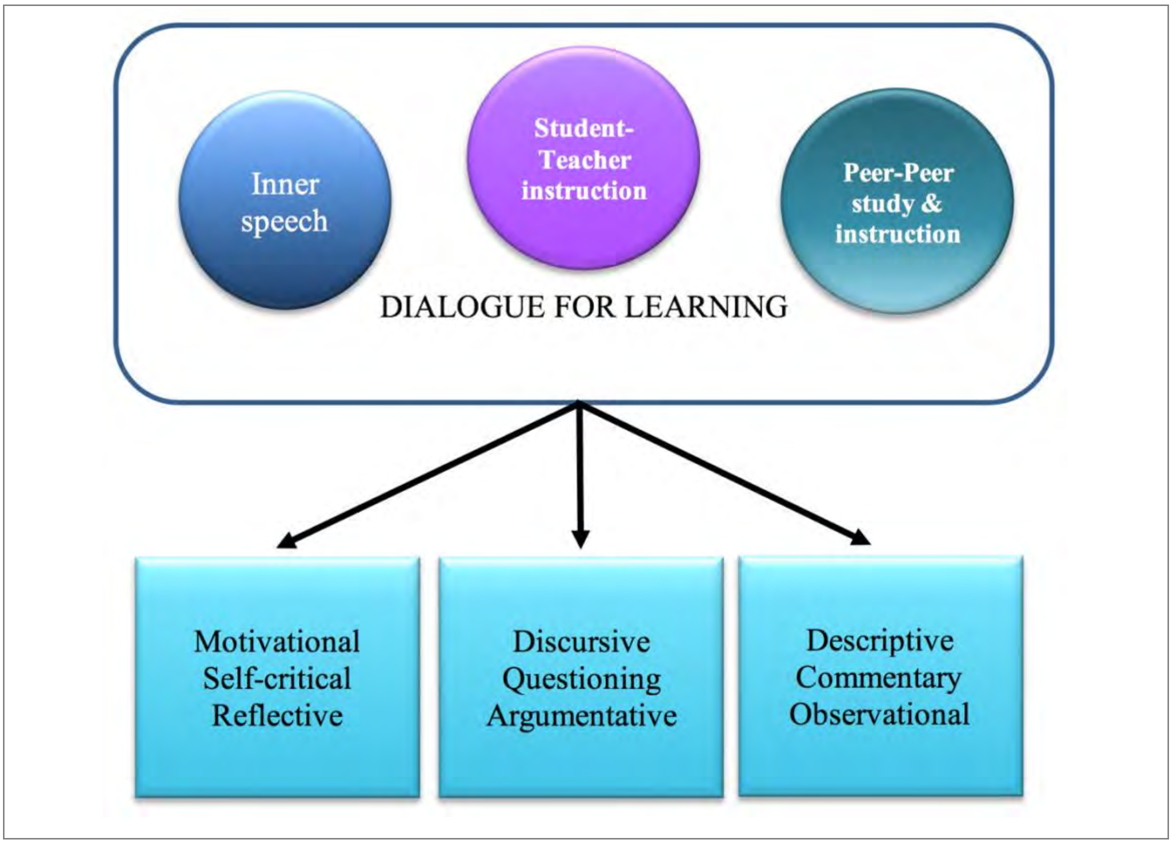

Figure 5.1 Depiction of the main processes of dialogue for learning

5.3 LANGUAGE FOR TRANSFORMATION

From my research data I have demonstrated three major sensory inputs that shape student conceptual learning, these are: language, visual and emotional experiences. Semiotic mediation modalities such as language have an important impact on conceptual learning and memory, but, so too can emotional experiences and visual learning processes. This relates well to the known elements of cognitive processes as detailed in recent psychological studies. When alone, some students prefer external voicing of a teaching-style role play, and if in a public space (e.g. the library) they might speak this in their mind, with their lips moving and sub-vocalisation occurring. For these learners, this active voicing of their thinking appears to enable them to become more conscious of their thoughts, to stimulate more effort in thinking, so their thoughts are more transparent and hence more easily manipulated, especially when they are struggling.

Certainly, it would be useful to know what is happening in the brain when the inner voice assists with conceptual learning. The latest research suggests that there is involvement of working memory activation and other internal brain loops (Fernyhough, 2016). For example, the phonological loop model (Baddely, 2010, p. 139) suggests that working memory connects longer term memory to the auditory and visual (written and image) inputs that are useful for conceptual learning, language learning, and so on. These loops are stimulated by external speech and dialogue – so that they can hold the thoughts and related elements to be processed for longer (Alderson-Day & Fernyhough, 2015). In the multicomponent model of working memory (Baddely, 2010, p. 138), the episodic buffer may well be how students are consciously initiating further learning: by stimulating the use of the buffer through the use of dialogue (internal and external) and active self-questioning, concept-mapping and so forth. These loops are still unclear, but somehow the mind is thinking for transformation. The Vygotsky-TCF framework was applied to the data, specifically to outline this process in detail for critical thinking processes.

In examining Vygotsky's concept of intellectual perception, it is clear that he emphasises the central role of language and thinking in the development of these new, transformative, gestalt-like understandings that derive from new ways of perceiving and practicing disciplinary knowledge (Michell, 2016). These insights can be sudden, break-through threshold moments that signal ontological as well as epistemic transformation in the learner. This can extend our understanding of the threshold concept to take in more, to become threshold insights which allow the learner to change their whole way of seeing and understanding disciplinary knowledge and practice. A powerful example of this has been given earlier in Kennedy's (1998) account of his own revelatory experience of understanding of the key statistical threshold concept, sampling (Bulmer et al., 2007; Downs & Robertson, 2015; Quinnell & Thompson, 2010). He was able to see where his students were 'getting stuck', as he had experienced a similar moment of inability to learn, that was powerfully changed by transformational conceptual understanding. Kennedy's rich description (provided in Chapter Four) draws our attention to the impact that these threshold insights can have on the ontological as well as an epistemic transformation happening to the learner, and it sheds some light on the successful journey across the learner's liminal space.

Moreover, I note the importance of mental models in this process, as facilitated by language. Vygotskian perspective on mental models for manipulation and problem-solving is relevant here, and the visual-auditory-language triad is relevant to current interpretations of Vygotsky's theories, as explained by Langford (2005, p. 186):

> Thought in Vygotsky's sense means the rearrangement of image-like mental representations to solve problems, which is what occurs according to the mental models view of reasoning. …in order to solve problems from formal logic, not only children but also adolescents and adults translate the problems into picture-like models and manipulate these models to solve the problems.

Vygotsky proposed that mental images and models played a key role in mental problem-solving and logic. It seems reasonable to expect that these images and models can be used for other learning and critical thinking purposes.

5.3.1 Language as a Study Tool

Language appears inherently involved in the students' teaching-learning, as inner and external speech to self (dialogue, questioning, motivational, observational, inferential) and the more 'ordinary' external speech as dialogue with instructor or peer that seems to be central to the process of conceptual learning. Within these data, many mentions were made by students of other tools and signs being of use in their conceptual learning, including textual, conceptual mapping, conceptual language, audio learning and verbal-textual memory aids being used as study tools.

Reading and Writing

In terms of reading and writing, some students were certain that this was their main, most efficient way of learning. Several student cases mentioned re-reading and re-writing of lecture notes, the writing of revision lists and layers upon layers of notes. Students often admitted combining the written and reading modes of learning with talking. Even, when thinking an inner dialogue, Case 2 stated that he was also writing it down. "I think it's always about breaking it down and scribbling it while talking" (Interview 2). Whereas Case 8 said: "I can't write about this and that in the same paragraph which will make sense even if I read it. I find it so much easier to give feedback, reflect on myself, reflect on feedback when it's more verbalised" (Interview 1). At the same time, when talking about thinking "vacantly" on the bus, he said "when I talk or write or read something that's stimulating, I'm actually actively thinking about these things and that will be stimulated then." So, both writing and reading were stimulating active thinking, but for this student these didn't have as much impact as self-talking. The transformative nature of the reading and writing was not very clear in my data, but note-writing, the active thinking use of drawing out flow diagrams and concept maps were often cited by the student cases as a useful means to clarify concepts and link them together.

Figures of Speech

Similar language-mediated perceptual transformation is also the goal of the conceptual mediation tools of analogy, simile and metaphor. Anchored in the personally familiar realm of our embedded spontaneous, everyday concepts, these figures of speech build on an age-old approach to concept formation; the known is used to explain the unknown, facilitating the crossing of conceptual thresholds to new perspectives and understandings. By employing these conceptual figures of speech, the instructor narrates a parallel story that connects the learner struggling with the new concept to concepts that are readily understood, and concretise the new and challenging disciplinary concepts encountered in the liminal space to foster new ways of seeing and thinking.

All student cases demonstrated how analogies and metaphors were useful to them in explaining new troublesome concepts. They recognised that this was effective as it tapped into their known concepts and general understanding of the world. This was not an unsurprising finding as it is a recognised teaching approach, which has had a revival in school-teaching and in higher education (Clement & Oviedo, 2003). The students themselves had quite memorable ways of describing their experiences of learning through analogy, although they did not always manage to succeed in the retelling of an analogy, suggesting that they had not completely understood all of theory or both of the concepts (old and new) used in the analogy. This student explains what analogy does for his conceptual learning:

> So, the reason you can't really understand something is because you're not really using the right line of thinking and if you use analogies it really just eliminates the wrong lines of thinking until you can find something that actually fits, like a metaphor that actually works. (Case 6, Interview 1)

This shows that analogy for him is useful to illuminate the way of thinking that is correct. A different student explains his understanding of analogy as drawing on the similar known and current understandings and thus offering a way into seeing the concept – a side-route into the unknown from the known:

> Yep, when you have an analogy I can draw parallels to other experiences I've had in life and then those experiences obviously make sense so if you tell me that's essentially that, okay, then I have an understanding of what that is because, really and honestly, in this

> whole entire world nothing is really completely different from anything, really, there's always similarities.

This seems to work partially even when the concepts are way beyond his understanding:

> Okay, sure, some concepts are really, really farfetched, really disconnected from anything I have known. But if you give me analogies to tap this from different perspectives and aims, I might be able to get some of it.

And later on, he explains further what happens when there are no possible analogies:

> Sometimes things are so alien that in fact if you haven't got any experience of it - maybe there is no analogy and you'll need little bits to actually get you there. (Case 8, Interview 1)

So, it seems that for an analogy to work, the understanding of the basic or everyday, similar concept has to be clear and well understood, or it has to be simplified across various steps, or this inability to understand provokes the student find their own explanation. For example, Case 2 didn't understand the analogy of the sonar radar 'signal to noise' ratio for the t-test statistic that I used in a lecture in August of the study year. For this concept, he preferred the formulaic explanation as he could not grasp the everyday meaning of signal and noise and apply this to the meaning of the formula. In contrast, a complex analogy that worked well for a third-year student was an apparently simple one on heart block that was explained in a recommended basic cardiology text book. This straightforward analogy of comparing different types of heart block to the way that people walk through doorways, had stuck well in her memory for at least 2 years:

> So, the first-degree of heart block is where they pause before they go through the doorway. The second-degree of heart block is where – the second degree of heart block, type 1, is where an occasional person just falls over [laughs]. And second-degree heart block type 2 is where they progressively get slower and slower until someone can't make it through the door. And the third degree of heart block is just … people can't get through the door. (Case 5, Interview 2)

She went on to explain that what made it memorable wasn't that it was an analogy of something simple (people walking through doorways), but that she had spent time with her peers discussing it, going through it, trying to work out which was which block, and fitting the different types of heart blocks to the right doorway analogy. Hence, this analogic explanation provoked and assisted an external interaction-mediated learning of the complex concepts that explain heart beat regulation and related pathology. As both the ZPD and liminal space are described as discursive, using analogy and metaphors of better-known conceptual understanding enables mediation that scaffolds from the learner's known concepts to the new academic concept.

Narrative

Another set of common tools used by the students in their learning was narrative-based, including scenarios, patient cases (real and fictional) and stories. This was evident across the data, including the expert interviewees who talked of the importance of using it to teach. Students reflected on creating their own scenario cases and narrative examples when struggling to understand key and troublesome concepts. Indeed, students clearly recalled specific medical scenarios used in teaching across Phase 1 and 2. Also, they found that real-life examples or cases were useful to learning, the more authentic the better. However, even simple or less authentic scenarios were helpful, so long as the student could relate to them, as shown by Case 7 in his journal:

> *I always found that applying the statistics to a real-life situation was beneficial. Didn't even matter if they weren't totally real. Looking at websites which used concrete examples, such as people or Martians (would you believe), always helped.* (Case 7, Journal)

Scenario, case or narrative examples applied within the activity or teaching context or developed by themselves were essential for making abstract concepts more distinct. In the focus group, as they were discussing how to grasp abstract concepts, a student proposed that even imagining a patient's clinical story or pathology assists in the visualisation, eventual understanding and also the memorising of that concept. "So that ensures that you don't lose that concept in the future – you have a place where you can go back and just recall all that stuff" (Case 5, Focus group). Furthermore, the clinician experts felt that the narrative approach was key to student learning as this was an essential element of the practitioner-based way of thinking that they were trying to instil. They considered that the patient's story is crucial to patient care, hence teaching with narrative needed to be both implicit and explicit.

Overall, these narrative-based approaches work well in assisting conceptual learning as they rely on the student's innate curiosity, their desire to find out more, and they stimulate interest with the attraction of the unknown, the inherent fun of detection and the inner reward gained on solving a problem. In addition, narrative relies on a story to capture more than curiosity, it also frames the learning within a digestible story, of a known or non-threatening structure and relating the novel concepts to known parameters within our lives. In this way, narrative performs a similar function to figures of speech, such as analogy. Jeanette Winterson, in her poignant memoir, *Why Be Happy When You Can Be Normal* (2012), explains how use of personal narrative can shift perspective by referring to her earlier semi-autobiographical novel *Oranges Are Not the Only Fruit*:

> Personal stories work for other people when those stories become both paradigms and parables. The intensity of the story - say the story of 'Oranges' - releases into a bigger space than the one it occupied in time and place. The story crosses the threshold from my world into yours. (Winterson, 2012, pp. 60–61)

Thus, in using narrative, instructors and learners "meet each other on the steps of the story" (Winterson, 2012, pp. 60–61), and, similar to the mediational use of analogy, the narrative has the effect of mobilising the learner's present understanding to reconcile this with the learning of new or difficult disciplinary concepts. McAllister, Lasater, Stone and Levett-Jones (2015, p. 554) explored the use of learning activities for nurses and found that these fictional narratives of health, ill-health and nursing practice provided an "important counter-point" to the usual objective, dry curricular learning of disease and practice. They found that the stories stimulated their imagination and engagement, whilst also moving students emotionally so that they gained more authentic experiences of illness, suffering and caring (McAllister et al., 2015). This thought-provoking research suggests another way to help health professional students encounter caring and illness in theory. This is valuable, as caring is considered to be a threshold concept for health professionals and one that is very important to learn (Clouder, 2005).

An interesting aspect of narrative, story-based learning is the listening element. As already mentioned, listening or hearing is vital in dialogue and inner hearing is an essential aspect of inner speech. This is a skill that we learn very early in our lives and is a key element to conceptual learning via narrative. This might explain why audio learning was a common theme amongst student cases, for example, the re-listening of lecture recordings, and also the use of visual-textual memory aids by speaking aloud to self and within peer study groups. Students often used flash cards and mnemonics in basic revision and study, but they admitted that this was to stimulate basic memory function via the audio route and so learn lists and definitions by rote. Both contrasting methods played a key role for the students in their preparation for exams.

This analysis suggests that, as with analogy, narrative facilitates the crossing of conceptual thresholds to new understandings, perspectives, and ways of thinking. By using fictional accounts and figures of speech, teachers can connect learners to familiar, everyday, spontaneous concepts concretising new and challenging academic concepts encountered in the liminal space. Narrative, analogy, and metaphor are effective meditational means for advancing transformational learning in these zones. Telling stories and examples, listening to stories and histories, and creating narratives for learning are essential conceptual learning activities.

The Visual Tool, Memory and Experience

Textual learning by listening and speaking was by far the most important approach to learning. However, strong visual learners tended to think actively and passively using diagrams, maps, flow charts, images, and visual metaphors and analogies. Concept maps and flow diagrams were actively used by student cases in their learning of concepts. Flow charts were even seen as visual thoughts:

> Case 5 (Interview 2): If it's in my head, I think with this, like in a diagram, like I always do. So, I think like a flow chart.
>
> Interviewer: So, you're seeing the flow chart do you think?
>
> Case 5: I wouldn't really visualise it in my head, but I think of it, like my thoughts come like a flow chart.

Furthermore, images and pictures were vital for many of the student cases to integrate their learning. For example, a first-year student found that going to the pathology museum and viewing the specimen pots was an important step in gaining a holistic picture of the disease, from its basic anatomy and histology (the macro/micro structure) through the pathology (what has gone wrong) to the clinical concept (what disease presents as and looks like in the patient post-mortem):

> *Seeing the specimens, I think often it does help when I remember, I think I was in the exam and there was a question about some anatomy concept, and I was trying to think about seeing it in the specimen.*
>
> \- - -
>
> *But once you've seen in the specimen, you're like, okay this is what it actually looks like rather than it being – because I think when you learn about it just now on a cellular basis probably a bit more theoretical. But when you see a picture of – we'll see in the museum it kind of, yeah, makes it a bit more real and tangible I suppose.* (Case 7, Journal)

Similarly, a self-confessed strong visual learner (Case 8) has a specific way of recalling conceptual understanding:

> I visualise all the concepts in my head, that's how I see things, information. I have this movie in my head, I can see the cells floating around and how things work and I can link up all the chemistry and physics and biology from high school, I can make sense of adhesion, of osmosis, it all works out. And this picture in my head, everything I learn I keep adding to it so this image, I can zoom in as much as I want and I can zoom out, I can see the bigger picture.

There was a surprising amount of detail in his memory using this method:

> But then if I want, I can zoom in into a smaller – just one cell and how the osmosis works or how the diffusion works, I can still remember the chemistry from Year 11 and all that and it all makes sense.

And he had insight into how this was functioning as a "platform" for all type of current and previous learning and conceptual linking:

> It's all there, and I suppose they're universal so this platform in my head, it doesn't matter if it's something in medicine or something physics-related or something that's different, it's the same because I'm using the same theory and knowledge that I have. So, the chemistry works everywhere so in my head all these, I suppose, simulations still work the same way. (Case 8, Interview 1)

This student's idea of a *platform* holding his knowledge is not dissimilar to a type of visual library of concepts, which relates to Vygotsky's imagery of the conceptual network as a globe with thought as movement occurring along and between the concepts as they lie on lines of longitude and latitude (see Figure 2.7). This student appears to have a good idea of the way his conceptualisation is organised in his mind and was able to see and reflect on how this was essential for his way of learning.

In addition, visual thinking can be used, just as language can, for gaining traction in difficult learning situations and for conceptual understanding. Some students have the ability to use an image to represent a word, containing its whole meanings, and are adept at using these visual signs when trying to fit concepts and ideas together in their heads:

> Case 8 (Interview 1): I can make a temporary picture if you use an analogy so you don't have to use the actual word prostaglandin or oestrogen or neutrophils or – if you gave the analogy of, say, this guy eats and he's a killer, he just kills everything he sees, then in my head I can have the image but– it's not linked to that word; but I still have the picture.
>
> Interviewer: So that term is not quite linked with that, but you can get what's happening.
>
> Case 8: Yep, because for me it's the doing, the action, as it were, the linking in my picture. It doesn't have to be the actual word for me. I can add the word in later, in hindsight.

Furthermore, cues, such as thought images are apparent in some learning experiences, used alongside the inner voice as questioner. A good illustration of this was when a third-year student was asked by a tutor about a surgical abdominal pain scenario problem, she found the answer was cued by an image in her mind of the four quadrants of the abdomen and her knowledge of the underlying anatomy. “Yeah, exactly, so then I have to kind of, like, cues for myself, so there would be the question and there would also be the visual cue that I always have” (Case 5, Interview 2). Visual analogies were also found to be useful for gaining traction in visually heavy disciplines, e.g. histology and pathology. For example, one student recalled with ease that the shape of a pig snout was used by a lecturer to describe the characteristic shape of atypical cells in breast carcinoma, “when I was looking up the histocytes, like, I could see the pig snouts and I can clearly remember what it is” (Case 6, Interview 2). Visual metaphors were the commonest form of visual analogy used and this was not surprising to me as I still remember from my own medical training 30 years ago what ‘sickle’ cells look like under the microscope. I still have a visual memory of the types of cells with these metaphorical monikers (e.g. sickle cell, target cell), but not of others. This linking of an everyday object with the scientific object, creates and maintains a strong memory link, similar to the way analogy works in verbal-textual formats for conceptual learning. A Vygotskian perspective applied here suggests that these are image-object mediators that rely on the student’s everyday visual-conceptual understandings to assist in their learning.

Another visual thinking approach used by many students were visual learning and memory aids or tools, such as the ‘memory palace’, concept maps, summary diagrams and various other uses of images in study. The students who declared these visual learning tendencies described using various mental mapping processes for the active learning concepts and spoke of actually seeing themselves in their inner mind’s eye integrating concepts, for example they used phrases such as “juggling’” concepts to see how they “link up” or struggling with mental images of concepts until they “fit together.” Overall, all the student cases had some visual inner experiences, and for some this was a dominant learning mode. These experiences were very positive, clearly assisting the visualisation of an abstract concept, delineating the complexities within a concept or assisting in fitting multiple concepts together to form threshold concepts or over-arching threshold concepts. Interestingly, there was no mention of confusion or troubled emotions around these visualisations.

The Importance of the Emotional Experience

As previously mentioned, emotional feelings were also a very important element of the student cases' learning experience and appear to play a crucial (positive and negative) role in the conceptual construction process. The emotional effect and response of the learning process, especially the negative effect of meeting with troublesome learning moments, was mentioned surprisingly often in the data and often acted as trigger points for deeper learning. These feelings were experienced by students as an indication that they had hit a learning problem and included: confusion, fear, uncertainty, irritation with self, and feelings of 'giving up'. In contrast, motivational inner speech acted as a trigger point for new attempts at critical thinking or taking a different approach or finding a different thinking state. Emotions at times were felt almost physically. At other times they seemed to play a semiotic role in the learning, in the sense that the emotion acted as a warning sign, an indicator, which then activated further learning responses, such as seeking external help or engaging self-motivational inner speech. These feelings were encouraging, helping the feeling of flow and diffuse thinking when everything was able to run smoothly, and students could feel good and satisfied with their progress.

5.3.2 Language for Critical Thinking

Despite often finding conceptual language difficult and troublesome, the student cases were forward in being able to identify language-related learning approaches that assisted their learning. Experts mentioned troublesome language in terms of student issues with conceptualisation. It was not clear how the troublesome nature of new terms might affect student's learning, but it seemed to affect their use of working memory for conceptual manipulations. Students indicated that when the new concepts are represented by a troublesome word or term, the anonymous and blurred nature of the concept was harder to handle in their thinking, as if it was hard to 'hold' or 'fix' in their mind or memory; they were trying to wrestle with its meaning and couldn't get beyond that. The term and concept were not exactly one and the same but were intimately interrelated. It is as if the new, tentative understandings a student has for a concept can't gain traction completely until the term itself has been fully assimilated. As previously discussed, this is not surprising as the TCF and signification theory suggest that this would be the case.

How students coped with this learning difficulty was interesting. As demonstrated above, if they didn't abandon or postpone the learning, then they implemented relevant semiotic methods or tools to overcome or alternatively bypass these semantic problems. Often, these study behaviours involved recruiting critical thinking skills to access other previously understood concepts to explain the newer concept(s). These assisted their learning as they either circumvented or explained the new word and its terminology by using terms that were readily or previously understood. The commonest methods were to use either simple or complex analogies, or to borrow terminology as metaphors or similes from concepts that were similar and more familiar. These usages of figures of speech act as linguistic bridges until the new terminology is better understood. They assisted student understanding by opening up their current knowledge, their Zone of Actual Development (ZAD) in Vygotskian terms. The other main approach was that students applied more powerful critical thinking skills in a complex process to carefully unpick what they did know or could grasp from the disciplinary topic and then build it back up again to a semblance of what they thought it should be. This critical thinking process included applying simplification and categorisation approaches to break down the concept into more recognisable parts that could be analysed more easily and made meaning of. Once they had understood these basic elements, they had to put it back together again, which was a much harder process, involving higher order critical thinking. To achieve a successful reassembling of the elements of the concept into something that they understood as a whole, students were using the specific critical thinking skills of explanation, integration, mapping and or synthesis. This is examined in more detail in the next chapter. Here, I will discuss more precisely the evidence and theory behind how students facilitated entering this process using language.

Linguistic Bridges for Conceptual Learning

Findings from the cases demonstrated that language was specifically used to engage critical thinking for conceptual transformation. This suggests that critical thinking relies on signification for conceptual transformation and that critical thinking uses the inner voice for learning and support in conceptual struggle. For example, a student described how his inner speech is central to both the inner and external private speech in everyday thinking and in conceptual learning. His explanation echoes his own appreciation of this difficulty in clarifying what is going on and how it can resolve understanding:

> when we're thinking just internally you first come up with the question and then – and it's, sort of, your thoughts around the topic. But when you're talking it or teaching yourself the two are sort of simultaneous – you're sort of talking and speaking

> information, either through just reading it or just blurting out whatever you can. At the same time, you're thinking up a few questions as well. And I think that combined process helps to form links together and then comes this understanding. (Case 6, Interview 2)

This student reasons that there is a combined effect of inner talking as questioning and the inner hearing or answering modes which initiates integration. This resonates back to developmental learning and relevant Vygotskian childhood stages when learning about the social word revolves around social dialogue, which then develops into an internalised tool-sign mediator for conceptual learning (Wells, 2007). This inner dialogue was inherent to all of the students' learning approaches; students mentioned experiences that were similar, but also at times these were quite different. Moreover, every student reflected on this as a positive process for conceptual learning. Some thought this to be almost ubiquitous:

> I do it all the time. I somehow have this conversation with myself, a two-way conversation and there is this part of me who is this devil's advocate, challenges understanding things. (Case 2, Interview 2)

So, inner speech as inner talk is being used often to create an instructive situation whereby the inner voice is challenging understanding and thence to learn more deeply, using argued explanations supported by known and understood evidence. The process I saw here is similar to Entwistle's model (2003, pp. 4–5) where the learner progresses through levels of understanding from the basic level of being able to mention and describe the concept to being able to relate it (using personal but less substantial evidence), to clearer explanation (using relevant evidence in structured arguments), and finally to conception of the topic (through reflection and transformation). Essentially, this inner speech process is the deep approach to learning that Entwistle and others have advocated over the past two decades, and this fits well with the TCF as a method of conceptualisation. Also, it fills a void in the Vygotskian learning zone as to how the instruction scaffolds learning within the ZPD from the basic, current (actual) learning level to the transformed level that becomes the new ZAD.

Further analysis of another student's second interview revealed this process in full. Case 1 said that he used a self-teaching approach specifically for talking himself through the steps of conceptual explanation, but this needed to be an active 'talking' process:

> When I'm talking to myself it's very similar to when I'm talking - if I'm talking to someone in order to explain that new concept, - - - because when I'm talking to myself, I'm thinking of myself as another person… (Case 1, Interview 2)

So, he realises that he is using dialogue to self – conscious or semi-consciously. He went on to explain that when he meets a new concept, he starts by finding out what he does and doesn't know:

> …So basically, I think essentially when you're trying to communicate with yourself you are picking on your particular faults, the particular gaps in your knowledge and then you are trying to… [unfinished, pause] - and then you yourself are trying to fill in those gaps by means of the new knowledge that you receive… (Case 1, Interview 2)

This is equivalent to testing his ability in terms of outcomes for Entwistle's model (2003, pp. 4–5). Monitoring the development of one's own understanding, as well as the effectiveness of one's study strategy are both key to this model. Inner speech used in this manner, can do this critical reflective job very well. Going onwards in the same way, the student describes how he talks to himself as he would talk to someone else to explain it to them, or teach them by elucidating it into more basic concepts or steps:

> …So yeah, I think I am - me talking to myself is going to be really, really similar to me communicating with someone else to talk about a new concept, and what I like to do is I try to break it down into steps… (Case 1, Interview 2)

This dialogue relates well to Entwistle's fourth level of understanding (explanation). For this example of teaching himself about a physiological concept from a lecture on homeostasis, he:

> …tried to break it down into sequences, like what triggers homeostasis … - how is the coagulation cascade activated – and what are the basic measure steps of forming a blood clot and what essentially happens after you have formed a blood clot and you want healing. (Case 1, Interview 2)

Breaking down the physiological process allowed the student to apply critical thinking skills to smaller parts and thus make it understandable. For this student, this process was internal, unvoiced, speech and key to the process was the initiation of critical thinking action of simplification of the concept; the breaking down of the complex process into steps that were easier to understand. This will be examined in more detail in the next chapter.

For some students their inner speech was predominantly questioning, and it can be presumed that mostly this was used for initiating deeper learning experiences. Cases 6 and 7 seem to be aware enough of the inner speech processes to notice that they were experiencing dynamic self-questioning when they met a challenging learning situation. Case 7 recognised that he had been actively questioning his knowledge of the statistical threshold concept of central limit theorem as he had found this “confusing.” In the interview, he reenacted this self-questioning process, showing how the questioning helped provided answers for building up a better meaning of the concept:

> So, there was always a question of why? – why? – why? with the CLT. Okay. You took the averages, but why did you take the average? Okay. You have the mean knowledge distributed, but what significance does that hold? So, there was all these questions. And, I think, being able to answer one of those questions helped answer a few of the other questions and connect; if that makes sense? (Case 7, Interview 2)

Unfortunately, on further questioning, he was not able to explain any further detail as to how this process had happened in his mind. His inability to see how this happened suggests that it was less volitional than he suspected. This form of self-questioning is not very formal, is unprepared, and is not asked verbally in a full question and answer format but posed internally in a compressed inner speech manner. The involuntary nature of the process was appreciated by the second-year student with the character-based process mentioned earlier: “Yeah, it's automatic. Somehow, I need to talk it out. I need to talk out loud, because I think no one else - not many people around me do that. It's a bit of both, yeah, dialogue and argument” (Case 2, Interview 2). And for a different first-year student, this experience was subconscious, although he thought it could be actively enhanced “because you’re subconscious – I don’t know if subconsciously… or if you’re just thinking of questions outside of your mind as well as elucidating answers or possible answers and links” (Case 6, Interview 2).

However, although they recognised its uses, this inner speech argumentative-explanatory learning method was not as important for all the students. In contrast, the most mature student (fifth-year) had an interesting viewpoint of her use of inner speech, in that she employed inner speech actively for decision-making, but the inner speech then worked subconsciously for her learning, finding herself in that:

> ‘other state’ where it’s interacting with the information without really being aware that you’re thinking of it…you’re not even aware of yourself. You’re just, kind of, lost in that abstract world of information that you’re trying to put together. (Case 3, Interview 2)

Also, for the third-year student case, visual thinking was dominant, but even so, she realised that she used self-questioning with a logical approach to gain better understanding and a firmer memory of a concept. "Yeah, if I make a definitive statement in my head, if I say it to myself and like, if I say it to myself, A will lead to C, do you get it? Then I will remember it" (Case 5, Interview 2). A couple of students recognised that they were experiencing conceptual learning as inner speech at times but did not seem to have inner talk as conversation or perhaps did not recognise the inner speech or their own inner voice. This aligns with research that shows that not everyone recognises or perhaps has these inner speech experiences (Fernyhough, 2016). Presumably their learning was through other more visual or auditory means.

Another wave of abductive analysis was carried out on the interview data specifically to identify teaching moments around troublesome and transformative learning. Unexpectedly, there was less to find that directly mentioned active teaching elements or experiences and inner speech. A third-year student (Case 4) reflected on a tutoring experience. He was tutoring an HSC student in mathematics, and the dialogue that resulted with the student helped him grasp a mathematical concept he had never before fully understood. The HSC student was talking aloud through his own understanding of log functions and it was only then that the medical student realised that his own understanding was at fault, and he saw a completely new way of looking at it:

> Case 4 : Well, it was partly the thought processes of the student them self and the piece-by-piece moment when he was working, trying to piece together what his teacher had taught him.
>
> Interviewer: Okay. So, was he talking out loud?
>
> Case 4: He was talking out loud and it was very patchy, so to speak. And then it helped *me* piece together his logic with the information that I had myself. And, so it developed into some kind of continuum, so to speak.
>
> Interviewer: Okay. So, what did you feel like at that moment? …
>
> Case 4: Well, there was definitely both relief and satisfaction. But, I suppose, a consequential spur of confidence, maybe.

This example adds to previous data presented on dialogue during teaching and learning, but, furthermore, it suggests that the process of listening to someone else's private speech can initiate one's own learning process, in a similar way to one's own inner thinking can.

Overall, this deeper analysis of the data revealed how language facilitates deeper learning for conceptualisation. My cases were utilising various linguistic bridges to move into higher level thinking for learning concepts. This includes directing questioning at their conceptual learning via an inner teaching mode; using active self-dialogue (unvoiced or voiced, characterised or a 'self' voice) to describe, clarify and explain; and introducing an inner hearing mode into their thinking processes to activate further working memory and critical reflection and deeper learning. It appears that language is the key stimulator of deep conceptual learning via the listening-talking brain pathway loops and activation of critical thinking processes.

Language Provokes Intellectual Perception

There is good evidence to support various purposes of inner speech, including making conscious thought, actively promoting self-awareness and reflective practice, helping with memory retrieval, and applying reasoning, abstraction, decision-making, problem solving and other cognitive processes (Desouza, Dasilveira, & Gomes, 2008; Frankish, 2018). There is interesting theorisation, but less published research around the processes of inner speech for these thinking purposes. Another area that lacks a good research base is the examination of instruction and peer-learning in external speech as dialogue and discourse, and how these ways of learning compare, contrast and connect to inner speech as used for inner talk, self-questioning and self-teaching. This intriguing query led me to look further from older to newer theories about dialogue, inner speech and thinking.

Vygotsky (2012, p. 242) theorised that inner speech "…does not merely accompany a child's activity; it serves mental orientation, conscious understanding; it helps in overcoming difficulties; it is speech for oneself, intimately and usefully connected with the child's thinking." Further, Michell (2016) has drawn attention to the importance of the intellectualisation of perception as this shifts our "way of seeing things" (Vygotsky, 2012, p. 181) and this is "how the processes of thinking and processes of perception merge" (Vygotsky, 1998a, p. 88). It is perception of the meaning of things that brings this change about: "The shift to a new type of inner perception means also a shift to a higher type of inner activity, since a new way of seeing things opens up new possibilities" (Vygotsky, 2012, p. 181). Vygotsky (2012) illustrates this concept of intellectual perception further with his analogy of how adult and child players 'see' a chessboard differently according to their different levels of knowledge and expertise. Intellectual perception means that a:

> chessplayer's moves are determined by what he sees on the board; when his perception of the game changes, his strategy will also change. In perceiving some of our acts in a generalizing fashion, we isolate them from our total mental activity and are thus enabled to focus on this process as such and to enter into a new relation with it. In this way,

> becoming conscious of our operations and viewing each as a process of a certain *kind* – such as remembering or imagining – leads to their mastery. (p. 181)

Furthermore, Kozulin and Presseisen (1995, pp. 68–69) explain that Vygotsky's proposal of words and language was established to act as "psychological tools" in our minds, to transform the thought processes to create a higher level of mediated mental functions. However, they suggest that Vygotsky did not explain adequately the activities of the human mediation occurring in the ZPD, hence the later work on mediated learning experience and instrumental enrichment that they go on to describe (Kozulin & Presseisen, 1995, pp. 69–72). They propose that Vygotsky's original idea of psychological tools and meaning-making can be extended to adult learning, which allows one to consider that critical thinking and conceptual learning are inherently linked, and that language is an essential element in this process; in fact, it would not, could not occur without it. The process appears to revolve around language as signification as a key tool in conceptualisation - which appears underappreciated in this field.

Recent psychological research into inner speech is beginning to demonstrate how this might happen. It appears that language actively and passively links thinking across the other mental experiences – the inner expressions of thinking as speech, visual, auditory and emotional learning (Martínez-Manrique & Vicente, 2015). In so doing it triggers the relevant critical thinking processes that allow the meaning-making, the transformation and the perspective shifts for the liminal threshold to transformation. Also, language as inner speech can have a positive emotional stabilisation effect, and a negative, inhibiting effect. Examining the data further revealed more insights into how language specifically aids conceptual learning processes; language for and in conceptual learning. Interestingly, in their proposals based on Laurillard's conversational framework (202, p.87), McCulloch and Field (2014, p. 4) advocated the use of "linguistic 'bridges'" to facilitate concept learning through activated conversations, iteratively advancing their first-year language students' understanding forward. This staged learning process was designed to promote the peer learning and learner-teacher dialogue to assist the basic understanding of threshold concepts. They saw this early acquisition of understanding as the beginning of the transformation process, "a kind of 'mastery-with-a-small-m' in the learning spiral that culminates in full mastery of the threshold concept" (McCulloch & Field, 2014, p. 7).

Data analysis using this abductive approach has illuminated how language as a cognitive, conceptual learning tool assists these transitions to higher mediated mental functions. By specifically examining how language was used by participants I have shown how language acts as a functional bridge to cross the gap between the known and unknown – between firm ground and new, uncertain ground. This is achieved using learning strategies and activities that present the knowledge (e.g. lectures, readings, tutorials, examples, exercises, etc.), which in turn stimulates external and/or internal speech that allows for the discursive, dialectic process detailed here. The next chapter will detail these more fully in terms of the ZPD. In conclusion, dialogue and inner speech are language tools for conceptualisation and stimulate critical thinking to support this. Identifying the skills that are needed here could aid learning and promote more effective signification making meaning, especially for troublesome conceptual transformation.

LANGUAGE-THINKING FOR TRANSFORMATION

Language is the main binder and link-maker across the brain networks for conceptual thinking; language, acts as the great communicator. It does this using both inner and outer speech, meshing with other formats such as visual conceptual imaging, mathematical and logical language and emotional capabilities. Language is the “thread” that links all the brain’s conceptual thinking (Fernyhough, 2016). This process is both active-conscious and passive-subconscious, and therefore not always apparent. However, it appears to underwrite most of our conceptual processing. Adding to this effect are the evaluative and motivator elements of inner speech, which are vital for the learning process and adequate student engagement (Alderson-Day & Fernyhough, 2015). Language as conversation, discussion and discourse, propels learning onwards through its use as a mediation tool, acting as the major linking mediator across the brain for the various modalities of thought mediation and inner language experiences (Fernyhough, 2016). Inner speech links up all of our experiences using language as the main connector-communicator. It functions like a telephone-operator with an old-style switchboard that connects up incoming ‘calls’, carefully and selectively to one or more cognitive systems in the brain network. So, inner speech and self-talk are actively and passively being used to link up the semiotic signs for conceptual learning to all the necessary mental areas. Fernyhough (2016, p. 249) describes this elegantly:

> Different experiences flow through our consciousness: visual images, sounds, music, feelings. But it is inner speech that strings them all together, allowing distinct neural systems to talk to each other by virtue of the way that the internal language network plugs flexibly and selectively into other systems.

However, this process is not observed in all people, and it is not clear how it works except that inner speech and external language are a vital part of this as part of the subconscious/unconscious thinking-as-language communicator that connects the brain's main conceptual areas via sign modalities.

In conceptual learning, critical thinking is stimulated and supported via these semiotic mediators. In more experienced learners, the brain seems to know which critical thinking process should be applied with voluntary choice involved or through more automatic settings. Interestingly, certain types of critical thinking are applied by some students and not others. Also, some students are aware, and some are not aware of the process as it takes place. The analysis identified specific critical thinking skills that stimulate the essential conceptual making-meaning that leads to conceptual understanding and, ultimately, to the transformation in threshold concepts. These skills are simplification, categorisation, interpretation, assessment, evaluation and explanation. All of these higher-level critical thinking processes promote synthesis, integration and mapping, and are usually initiated once the basic understanding of the steps or concept parts are understood. Underpinning all of this is student government and autonomy. Reflection is used as a critical thinking skill with self-direction and self-efficacy approaches used as a feedback regulator on the learning process.

One powerful language-based strategy mentioned by all case participants was language-thinking-learning as story and narrative. The importance of narrative in the data is demonstrated in this chapter and I argue that this is based on life-long cultural saturation of social narrative throughout our developmental and learning processes. This feeds the language-thinking-learning process. Without language, there would be no conceptual learning and no ontological development to a way of thinking and practising. Language is the central communicator acting as the teacher-learner across all of these processes. In conclusion, language-thinking is critical for conceptual learning. Language achieves this as it is the great communicator across the brain; linking and facilitating the cognitive processes that result in conceptual learning. The universal communicator is language; indeed, thinking is language. When this language-thinking is applied critically, transformation is more likely to result. Hence, the theoretical framework used in this thesis becomes refined as a language-thinking model with critical thinking included as essential to the transformation process. Figure 5.2 below summarises the main elements influencing critical thinking for transformative conceptual understanding.

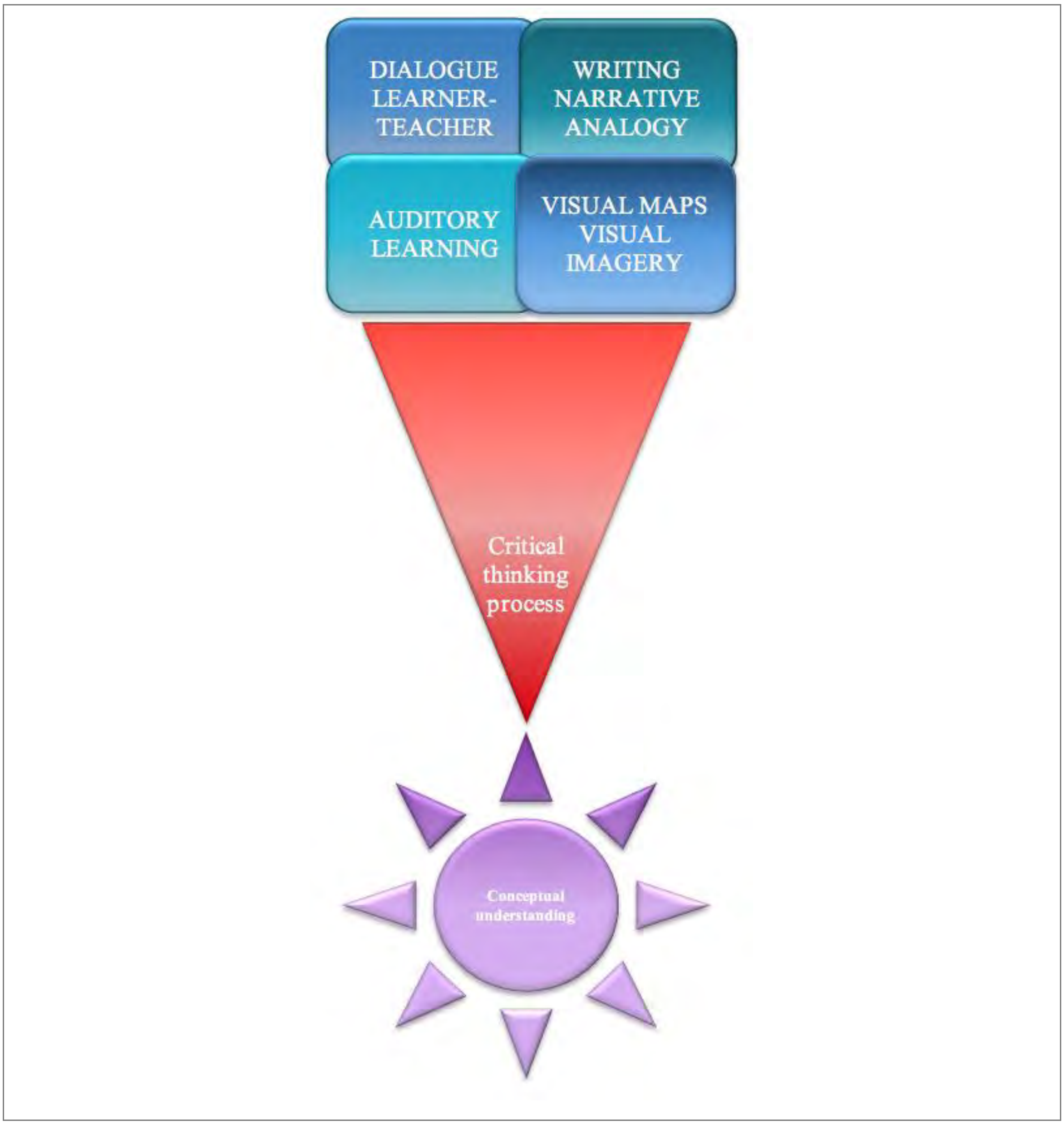

Figure 5.2 Language-Critical Thinking process for conceptual learning

CHAPTER 6:
THIRD INTERSECTION – THE ZPD/LIMINAL SPACE

“What the child can do today in cooperation and with guidance, tomorrow he will be able to do independently.”

(Vygotsky, 1998c, p. 200)

My research has found that Vygotskian theory and the Threshold Concept Framework (TCF) have startling and useful theoretical equivalences and intersections, which were harnessed during the analysis. The third intersection is where the two representations of the transformational and developmental learning spaces, the zone of proximal development (ZPD) and the liminal space, overlap. The aim of the final abductive analysis phase was specifically to explore further how a learner’s critical thinking assists in this transformational process, so as to illuminate the under-investigated ‘black box’ of transformation in this ZPD/liminal space. Hence, this chapter summarises the findings of the second research question, “What are the critical thinking skills that enable this troublesome transformational learning for medical students at UNSW?” and addresses the third thesis research question, “How does a Vygotskian/TCF framework approach add to the understanding of transformational conceptual learning?”

6.1 A DYNAMIC PROCESS

A major point of similarity between the Vygotskian and Threshold Concept frameworks appears to be that they both identify thresholds as playing a key part in the learning process. However, it is important to establish that the zone of proximal development (ZPD) is not concerned with the acquisition of knowledge, but rather it facilitates the socially-mediated development of the epistemic capabilities (higher mental functions) that underpin learning and thus promotes development toward higher levels of intellectual functioning. Therefore, it is characterised by intellectual transformation and development, marked by epistemic shifts and ultimately by ontological change that marks a substantial shift in expertise and disciplinary understanding (Vygotsky, 1997). In contrast, research into threshold concepts has focused on how disciplinary concepts are structured by the disciplinary knowledge, and thence how movement towards disciplinary expertise proceeds; the emphasis is on the epistemic shift, the mastering of threshold concepts as essential units of disciplinary knowledge and expertise. However, researchers investigating knowledge transformations (e.g. Mezirow, 1997), have brought a broader perspective by also examining emotional and ontological aspects of threshold concept learning, as well as its cognitive elements (Cousin, 2006b; Efklides, 2011; Land, 2016). Recent TCF research has focused mainly on the nature of the transformation that causes the ontological shifts and enables new "ways of thinking and practising" (Meyer & Land, 2003, p. 9). While promising, these developments are yet to clarify the detail of this conceptual learning process. The TCF's broader perspective of emotional-ontological transformation converges with the relational-developmental holism of the ZPD. Further, I surmise that the ZPD and liminal space portray the same learning processes albeit viewed from somewhat different perspectives.

6.1.1 Concepts – Connected and Integrated by Language

In Chapter Four, analysis of the interview and case journal data from all participants identified troublesome academic concepts: threshold concepts and non-transformational concepts (see: Appendix 4.2). Evidence was presented that suggested that the over-arching transformational perspectives were the 'master key' to a systematised network of transformative threshold concepts linked with other important disciplinary concepts and principles and skills. This whole conceptual process appears to be created by a complex learning process, aided by higher level cognitive skills, which are, in turn, guided by and conducted in language as the teacher, and language as thought. In isolating the constituent concepts of the overarching perspectives, experts generally agreed on which were troublesome concepts, but students were more likely to differ or be uncertain. This seemed to depend on whether the student had crossed the threshold yet for these concepts. Similarly, if students recognised that they had fully understood the concept, then they were very likely to notice (and feel) whether this conceptual understanding was a transformational experience or not. However, if they hadn't yet understood the concept, then it was impossible for them to tell if it was transformational, although they were clear if it was experienced as troublesome. Chapter Five proposes a primary role of language as the great-communicator in conceptual learning and, further, suggests that it acts as a guide and facilitator of critical thinking in its role in the learning process toward transformation.

Building on previous analysis, further abductive analysis was undertaken targeting participant's reflections and discussions around their experiences in learning the over-arching threshold conceptual ways of thinking and practising: 1) The EBP-Clinical Perspective; 2) The Statistical Perspective, a. Sampling, b. Understanding the Significance Perspective; and 3) The Research Perspective. Further themes were generated during this analysis that identified specific transformation aspects of ontological and epistemological change, e.g. "liminal space" and "perspective or ontological shift" (see: Appendix 4.1). The findings demonstrate that language and critical thinking act together for these transformational conceptual learning experiences.

6.1.2 The Conceptual Learning Journey

The ZPD has two cognitive developmental thresholds, the base being the current level of knowledge and understanding, and the upper being the prospective limit of their current understanding. If we apply this to the adult learner in a similar way, then at any given stage of development, a learner attempts to master new and challenging academic concepts, which they need help to understand. As previously mentioned, the learner initially develops an understanding of academic concepts as so-called "buds" of development (Vygotsky, 1978, p. 86). It is in the ZPD that the instructor helps the learner to master these concepts through instruction and provision of learning resources that relate these academic concepts to everyday ones.

In between these dynamic (often troublesome) learning points, occurs the concretisation of the concepts; the application of the new learning by putting the knowledge and skills into practice in real situations or authentic learning activities. Solidification and expansion of conceptual understanding are both aided by application in practice. By using supported learning activities as instruction, the zone of actual development border can be stretched to enable student learning (Chaiklin, 2003, p. 54). However, there are also learning points where consolidation, concretisation and integration of learning is necessary, such as "conceptual stasis points" for bedding down of the concepts understood (Kinchin, 2014b, p. 53). The clear moments of conceptual integration were identified as important by participants and so were analysed further. These are presented here as they contributed to my analysis of the whole conceptual journey as a "structural transformation of content" (Kinchin & Miller, 2012, p. 207); analogically an inner rewiring of concepts for new improved purpose. From a Vygotskian point of view this is where the learner becomes comfortable with knowledge and skills and the new conceptualisation assimilates as their zone of actual development (ZAD).

The abductive analysis applied across the whole conceptual learning process revealed some considerable similarities between Vygotsky's ZPD and the TCF's liminal space. Since they are both key moments of transformative, conceptual learning, an equivalence can be drawn between them. Identifying similarities between the zones of far and actual development, and the TCF liminal model is harder. If the post-transformative, post-liminal space is understood as a stage of conceptual consolidation following the grasping of threshold concepts, then it has the characteristics of the zone of actual development (ZAD). On the other hand, if it is understood as a stage of future conceptual possibility where the learner may see "glimpses at the edge" of their understanding, but not as yet fully comprehend (Berger, 2004, p. 350), then it has the hallmarks of Vygotsky's zone of far development (ZFD). The student cases illustrate this well, with their slipping in and out of understanding, their 'blurred' and 'fuzzy' understanding that was finally resolved on crossing the threshold into the post-liminal mode or ZAD. Figure 6.1 below depicts a representation of these apparent correspondences between the liminal space and the zones of development, with respect to the transformations considered in each zone compared to the mode of liminality.

Figure 6.1 Apparent correspondences between the TCF liminal modes and the Vygotskian zones of development

However, this diagram cannot depict clearly the dynamic process between and across these learning thresholds during the learner's conceptual journey. My final analysis of the data revealed three fundamental topographic learning elements within this journey: 1) learning is an active, dynamic and interactive process; 2) points of struggle and minor thresholds of understanding have to be dealt with along the way; 3) transformation is the final full understanding and shift in perception and 'ascension to the concrete'. Each of these three topographies are examined in detail in the sections that follow.

6.1.3 Stepwise Learning

The descriptions of conceptual learning within the TCF and ZPD research literature correlate well with each other and with the findings from my data. There is an overwhelming emphasis on calling this a journey, with motion through or across a space. The language, analogies and metaphors used in describing this dynamic process reflect the inherent way that we think about it. This is a journey, and the learner's role is active, with collaboration within the learning zone or space. Also, there is consensus that these journeys are exclusively individual. No two learning journeys can be exactly alike and this "inter-individual variation" (Felten, 2016, p. xxiii) was important for the approach to the study design, analysis and research recommendations. Most student cases (and experts) reflected on learning experiences as a step-wise process that added on and built up their understanding. Each step forwards indicates progress through the dynamic stages that are necessary to reach and undergo full transformation, with each step being as important (and often frustrating) as the last. Also, it is important to remember that there are moments of hesitation, forgetting, misunderstanding, dead ends, and necessary revisiting and reiteration for this learning to happen.

Experts showed surprising clarity around their transformational journey. For example, a clinician (with two master's degrees and a PhD), said of her undergraduate training in statistics, that although she knew that she had taken this as a full course subject, she couldn't remember learning any statistics at all. It was only when she did her first master's degree and handled "real data," that she remembered that first learning experience and realised how poor it had been. When she took the second master's degree, she finally felt that she understood statistics, but only achieved a "very low-level understanding." She believes that she only "started really understanding" statistics properly, when she had to teach it to students (Expert 3, Paired interview). This frank explanation of the development of her own understanding shows that, in terms of the theoretical framework, there are levels of understanding that are passed through as a learner, each challenge or instruction producing a further stage in understanding, until it seems as if there was enough of this conceptual network understood that it can "fall into place." She realised at the time that it would have been "nice to have known before," which is a classic threshold concept experience of finally understanding and being transformed by it (Expert 3, Paired interview).

Later on, during her PhD research, her expertise level increased, but she reflected that she still did not understand statistics fully. At this later stage, it seems that she was in a more advanced ZPD, with new instructors, different artefacts as learning resources and within a different cultural learning environment. At this point, she reevaluated her current level of knowledge and realised that she had more to learn, adding to her previous learning. Finally, the learner masters the academic concepts, by internalising, externalising, and concretising these so-called "fruits" of development (the ZAD) (Vygotsky, 1978, p. 86; 1987a, p. 208). This description provides good evidence for the layering and bedding down of her statistical learning that aided a final transition to a statistical way of thinking and practising.

As previously explained, when considering the conceptual learning in the ZPD, there are two thresholds. There is the lower level where current understanding is possible without assistance and the upper threshold when the learner develops conceptual understanding and meaning following instructional assistance. At the new level of development, the learner attempts to master newer and more challenging academic concepts that they need further help to understand (ZPD). To do this is not easy; this is where the intellectual struggle occurs. This expert emphasised that, in her experience, learning is a struggle that requires theory, but it also requires practical application and personal relevance for full understanding. For this expert, the higher-level statistical concepts and theoretical problems were a struggle to learn but were easier when scaffolded across several learning environments and challenges, for example, each of the masters' degrees, and then finally her teaching experience. Unfortunately, there was not enough detail on these steps in the interview to analyse her experience further, but one can surmise that each of her learning progressions could be considered transformational, initiating a changed perception. Additionally, she stated that she achieved those moments of transformation with assistance from her instructors. However, the challenge of the application of the concepts to the data was necessary also, both within her own PhD research and within the framework of the assessments for the master's degrees. She concluded that it wasn't learning to teach statistics that elevated her to mastery but the practical interpretation of basic statistical threshold concepts such as "significance and measures of association," within epidemiological and clinical applications (Expert 3, Paired interview).

Considering this process using the TCF, the liminal space for this learner appears to be equivalent to the ZPD, and this was refreshed to become the ZAD once the new understanding has been made. So, a new ZPD forms once the liminal space is crossed (the transformational conceptual change has taken place) and the student is once again peering into a fresh area of conceptual learning (ZFD) that is just beyond her reach if working on her own. What the data show is that the degree of this transition-transformation-development only becomes clear and measurable when the learner is able to apply her intellectual activity independently after a period of instruction by more capable others. This resonates with both the Vygotskian ZPD theory and related liminal space transformation theories from the TCF. Figure 6.2 below depicts how the dynamics of this development progresses the learner onwards in conceptual development and at the same time triggers the layering and consolidation of their conceptual understanding. If viewed through the TCF lens, this stepwise conceptual consolidation could be depicted as a stacking (or indeed the scaffolding) of the transformational liminal spaces as they are crossed as the student proceeds to mastery of the discipline.

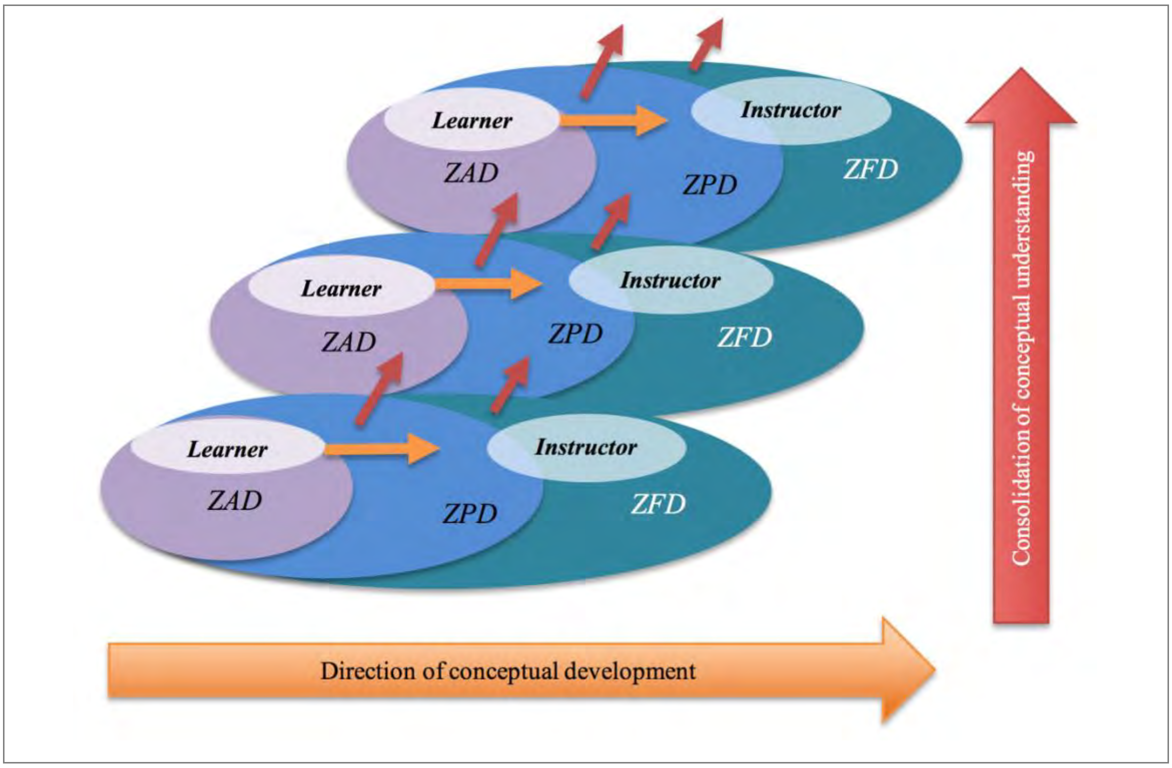

Figure 6.2 Visual representation of learner progression through conceptual thresholds as zones of development

(After Zaretskii, 2009, p. 82. Taylor & Francis Ltd: www.tandfonline.com)

ZAD: zone of actual development; ZPD: zone of proximal development; ZFD: zone of far development

In conclusion, it could be said that for Expert 3, her learning of statistics built upon each conceptual development with further understanding at every new exposure to the theory allied to application in practice. This consolidated and strengthened her understanding with each new move forward and upward towards expertise. Hence, consolidation of conceptual development over time increases conceptual development towards mastery and expertise. This useful finding fed into the abductive analysis for the student case data. When used as a prism to analyse across the student data from first year novice to competent fifth year student, it worked well as a simplified representation of the statistical learning progression of the students across the medical program.

6.1.4 Mapping the Journey Ahead

In moving successfully along this developmental learning trajectory, students were aware of the need to engage and be actively involved in the learning process. Moreover, students reflected that they would prefer to have a better idea of where they are heading in terms of their long-term learning and, more specifically, for the learning of each complex concept. Students were mature enough to recognise, from their novice point of view, that this learning is uncharted territory for them, hence their frequent experiences of feeling lost or confused. Curiosity, motivation and resilience in the face of this struggle were vital abilities to keep them moving onwards with their learning.

At the beginning of this journey, student cases frequently assessed what they already knew, what they were trying to learn and what needed to know. This was an automatic process at times, but this evaluation of their knowledge could be summoned at will in order to assess their situation. Often this evaluation revealed that they were not very knowledgeable, which tended to create panic as they realised that it would be impossible to assess what they needed to know, if they didn't know what it was that they were tackling. At this point they often felt that they lacked guidance across the journey – wanting a map or guide or to at least know the main learning 'pitstops' on the way. In Chapter Four, one of the most interesting and surprising findings was the perception that the students had of learning as a journey. Their vivid descriptions of these learning journey included road trips, webs and maps with territories.

Being reminded to reassess their progress at key points was also mentioned as a something that students appreciated. Formal, summative exams were most respected for providing judgement on their conceptual understanding as examinations grade and rank against expected standards. Formative tests, quizzes, questioning and discussion in class, with peer or teachers were appreciated also. Being able to reevaluate their learning progress in this way was useful as it allowed them to adjust and move on with their learning, or to seek help if they were genuinely stuck. Chapter Five revealed how getting stuck often initiates deeper learning, using dialogue with others and self to create more useful interfaces with the conceptual elements being learned. This seems to contribute to the smooth onwards movement of the learning journey. Findings will be shown later to demonstrate an intermeshing of dialogue and critical thinking in this process.

As explained previously, the ZPD is the learning zone where new academic concepts are engaged with and mastered, in a process where interaction of previously mastered academic concepts and the everyday thinking, spontaneous concepts leads to higher conceptual development and making meaning. Further, it is generally understood in the Vygotskian literature that the ZPD is the dialectic, troublesome learning space within which the 'disorganised' spontaneous concepts are systematised by the logic of adult reasoning (Chaiklin, 2003). The role of abstraction in this process is not clear from Vygotsky's writing, but he defined this as an abstract logical thought process that facilitates problem-solving and therefore initiates the initial, often intangible, conceptual leap to objective understanding that gives meaning to the abstract academic concepts (Vygotsky, 2012, p. 120). A typical example of how abstraction is applied to current developmental theory is provided by Howe's explanation (1996, p. 40):

> At the same time, the child must fit everyday concepts into the system learned in school, going from the abstract to the concrete and from the concrete to the abstract. Movement in both directions is necessary. The child moves toward understanding in a zigzag fashion, going back and forth between making everyday experience fit into the scientific conceptual system and applying the systematic construct to everyday experience.

This dynamic construction of conceptual learning from abstraction to concretion fits well with Vygotsky's idea of a dynamic relational zone, and also fits well with the TCF ideas of the mental travail experienced in the conceptual learning for transformative learning (Land, 2016) and the crisscrossing of the "messy journeys" that happen in crossing the liminal space (Cousin, 2006a, p. 5). How abstraction works as a critical thinking strategy for transformation is presented later.

6.2 DEALING WITH TROUBLESOMENESS

All the participants mentioned how these conceptual learning journeys are inherently troublesome and mostly difficult in some way or another. Interestingly, part of the pleasure of experiencing the final transformation of a threshold concept appeared to be mediated by the amount of struggle that it took to achieve this; similar to the joy experienced when finally reaching the top of a steep climb or mountain top. Student reflections, especially the journals and second interviews expanded on the emotional effects of their transformative learning processes, providing insight on their personal study approaches, critical thinking skills and learning activities that aided their transformation. Where they experienced emotion and 'trouble' was often where a barrier prevented or delayed their learning or transformation. Participants mostly agreed that learning for transformation required considerable personal input, and some trial and error. And, even though they differed in the personal learning approaches that they used, they all acknowledged the need for deep learning compared to superficial learning; they realised the importance of learning concepts 'properly' or 'fully' rather than just taking a rote-learning route. Mostly their journey was gradual and the final transformation momentary, as a third-year student reflecting on a classically troublesome statistical concept of the normal distribution reflected in her journal:

> *Emotions: While the learning process itself was gradual, when I finally understood specifically how one could produce a normal distribution from abnormally distributed data there was a moment of catharsis (a light-bulb feeling if you will).* (Case 4, Journal)

To get to this final destination is the troublesome part of the journey. Student data revealed three useful features of this journey. Firstly, this journey inevitably involved some form of inner conceptual struggle. Secondly, it was important for students to identify that their learning was troublesome as this led to the final factor, their implementation of various (successful and unsuccessful) strategies for transformative learning.

6.2.1 Recognising Trouble

A first-year student used the term "overwhelming" many times within his first and second interviews, and the terms "confusing" and "frustrated" were very commonly mentioned across all the data, for example: *"Confusion here. Frustrating, in fact*" (Case 2, Journal).

This student became more frustrated as he hadn't bargained on not understanding a concept:

> *Trying to figure out the definitions of the two validities took me almost fifteen minutes of frustration and that was as I did not plan to invest too much time in trying to understand the topic of surveillance.* (Case 2, Journal)

This process was often associated with anger and even mental anguish as recalled by another student, who said "it became quite painful for me" (Case 1, Interview 1). In trying to elucidate what was happening here, deeper analysis of the identified themes discovered that a different first-year student was having trouble with a concept when it was not intuitive:

> Especially – I guess those concepts that we only learned in HMA [a Phase 1 adult health course] and I'd never heard of [it] before and never had any concept of [it] before. Things like degrees of freedom. I remember, particularly, just having like a lot of trouble with because it was something that I'd never seen before. But it wasn't as intuitive for me. (Case 7, Interview 2)

In addition, students seem to expect some emotional trouble when they meet a troublesome concept which might inhibit the effectiveness of their learning approach, as illustrated by this journal reflection:

> *One thing I realised about myself is I rarely have a 'I got it' moment during the initial learning session; I tend to ruminate, get frustrated, sometime giving up, and suddenly I've got it.* (Case 2, Journal, audio recording)

Overall though, as noted in the previous chapter, students appear to accept these feelings as a useful indication that they don't understand and so need to go deeper in their learning even if it is "overwhelming" (Case 1, Interview 1). Indeed, a first year describes this emotional learning experience succinctly as he traversed from struggle to comprehension:

> *Affirmed my understanding of what threshold concepts are – where you mentally struggle with a concept and have to focus completely on it; may be concentrating for a significant period of time (30-90 minutes) before understanding it and a sense of relief and satisfaction runs through you*. (Case 7, Journal)

Recognising these emotions and troublesome learning points was important in triggering deployment of other learning strategies to keep their learning moving forwards. Hence, once a struggle point is recognised, a strategy is needed to assist the learning, otherwise, sooner or later, the learner is dissuaded and gives up. "I just disengage from that topic and I just move to something else" (Case 3, Interview 2).

6.2.2 Strategies for Troublesome Learning

Struggling often initiates a shift to deeper learning and student cases were aware that they needed to use skills to think deeper, to go beyond memorisation and rote learning. However, they recognised that they were not always ready or in a position to do so, due to time-pressure, or oftentimes they felt that they are not ready to understand, for example "it was sort of hard to grasp this concept" (Case 1, Interview 2), and "I definitely did get stuck quite regularly" (Case 4, Interview 1). Not surprisingly, within these difficult and often emotional situations the students were able to reflect on their critical thinking skills less easily than I had hoped. However, talking through their learning experiences, they were able to share useful insights into their critical thinking abilities; they described using triggers for deeper learning as a way into understanding a difficult concept – either by breaking it down (a type of conceptual dissection) or by using it (a trial of understanding).

In using a Vygotskian nature analogy, this is similar to the experience of coming across an exotic fruit that you have not met before. From the outside of the skin, it is hard to see what it consists of or what it tastes like. You could cut or split it open and dissect it to find out what it's like inside. You could try it out, by tasting it. Extending the fruit analogy further, certain fruits would more easily be understood by opening them up and dissecting (simplifying) them, if they are a complex berry or a segmented fruit. In discipline terms, this might, in physiology or biochemistry, be key metabolic pathways, where there are lots of steps as concepts and separate linked pathways to understand their connection. In contrast, where a fruit is simple, such as a banana (e.g. a simple concept of a database), with no segments or parts, it might be better just to taste it in order to experience it. Indeed, my analysis suggests that the conceptual learning process seems to be a synthesis of rejection, revision, blending, and fusion of concepts (analogically a kind of Vygotskian mixed fruit juice blend), with the ultimate aim of transformation following the epistemological and ontological shifts of the liminal crossing (Land et al., 2005).

Critical Thinking for Troublesome Concepts and Ideas

As previously noted, the student cases had many ways of thinking and employing skills in their learning. Considering that there were only eight cases, this suggests that there will be more individual approaches in a program with 270 enrolments per year. So, a teacher should (in theory) consider every student separately in terms of their critical thinking and the support they need. For example, Case 2, in his Journal entry in July describes a struggle with learning the complex threshold concept ideas of Type 1 (“TIE”) error and Type 2 error (“TIIE”) and power:

> *Let’s try making a simple cause and effect note:*
> *Low TIE > Low Power > Higher TIIE*
> *I understood the latter consequence but not the former.*
> *Hmm… I’ll give up for now.*
> *>**assessing claims and arguments** - Low TIE > Low Power > Higher TIIE. I can’t just accept this is true unless I understood why<*
> *>**self-examination and clarifying meaning** - in order to understand, I examined my current understanding so far on the concept of power and the two errors. Suffice to say, that it is likely that my understanding is weak<*
> *>**synthesis, presenting arguments and drawing conclusions** - looking at the notes above, I tried to explain to myself, but I obtained a different conclusion. I’ll have to discuss this with someone to get further clarification<*
> *[**wave of feelings** - started with confusion and discomfort, followed by momentary hopefulness when I tried to self-explain the concepts, and confusion again. The cycle continues until I decide to give up for now].* (Case 2, Journal, emphasis and notation in original)

This student reflection reveals his use of at least seven different critical thinking skills in three steps for his understanding of the concepts. He began with assessment of claims and arguments to see if he understood the concepts implicitly, but he realised he didn’t understand. Then he moved on to examining them in closer detail, but this didn’t help. So, he used learning resources to see if he could unpick the concepts enough to try to explain it to himself in a more simplified state and then build the concepts back up in his mind, but he recognised that he couldn’t achieve this either. This was accompanied by strong emotional feelings that eventually initiated a halt to the learning. Observing the process that he undertook as a whole, he made little progress on his own, yet the method he employed of drawing on his critical thinking skills and other learning resources appears very sensible.

Similar processes were reflected upon many times by other students and experts. A good example came from the most mature student, on describing how she moves from categorising and visualising the links to integrate them:

> I think it’s almost in the perspective in which I see things, I think I categorise things and see the relationships between things, and then once that’s clicked, it’s that perspective in which I see it. So, I assume it is knowledge in my head, the way that I appreciate it, is

> that it's in the perspective in which I look at different problems or clinical situations that come up. (Case 3, Interview 2)

Further, this shows how her current knowledge perspective influenced the way in which she was able to tackle the learning. This harks back, once again, to the Vygotskian idea of layering of knowledge and building upon previously understood knowledge including spontaneous concepts. The following outline describes three initial critical thinking process steps used by the student cases when meeting troublesome conceptual information.

Step 1: Assessment of the Situation

On encountering a complex and/or troublesome concept, the student's first response is to assess the situation: What do I know about this? What don't I know? What do I need to do to understand it? This is only partly conscious; there seems to be an almost automatic learning response that activates on hitting trouble in learning. Chapter Five described in detail the varied self-questioning techniques used to by students for this step. Once these students have a good idea of their understanding of this concept and their previous knowledge, they tend to move on to creating a sensible plan for the next step. They have experience in learning, so they are drawing on past experiences to map a way forward into this uncharted territory. The critical thinking here involves evaluation, clarification and self-reflection, mediated by inner speech and initiating motivational self-talk. A decision has to be made as to how to proceed and using what tools and artefacts.

Step 2: Readying for Abstraction

As mentioned above, the data suggests that a troublesome concept (e.g. statistical significance) can be found to be too complex or opaque for the student to grasp completely. Explicitly, students stated that they find it useful when the teacher breaks down or simplifies the concept so that they can then visualise and consider the conceptual constituents. Alternatively, students readily approached this themselves by applying the same critical thinking processes of categorisation and simplification. Students were very creative and worked to their strengths. Some students talked of creating lists of sub-concepts and processes, whilst other students drew diagrams, sketches or concept-map processes for the underlying processes or knowledge. All students spoke of how this process, if done well, allowed the whole conceptual process to be comprehended, visualised (if drawn or imagined mentally) and eventually understood. Clearly, this is a key step toward the Vygotskian phase of *abstraction* that he believed was required for the making meaning of concepts. However, my analysis showed that this step of the process relies greatly on the ability of the student to rebuild these separated elements together to form a conceptual whole via abstraction or other techniques (as detailed later).

Step 3: Evaluation of Progress

This final step in the troublesome learning phase takes a closer look at the simplified concepts and takes the student into the next phase of the journey: the transformation. This third step is often triggered and facilitated by further questions from instructor, peer or self, and by following examples or attempting exercises. At this point, students begin to conceive the function of the concept in step-wise or simplified way. A surprising finding was that students have different ideas of what this means and how they are using it for learning.

It is important to note that these three critical thinking steps (as portrayed in Figure 6.3 below) aren't used all the time but are commonly applied at the troublesome struggle points to initiate a move to deeper learning. The other strategy used by students was to alter the thinking environment to be more conducive to learning. This was declared as a useful strategy by all students and is described in more detail in the next section.

Figure 6.3 The pre-liminal critical thinking steps to initiate transformative learning

Thinking States for Troublesome Learning

As described in the previous chapter, another key finding was that most students mentioned the need for focus, calm or a quiet moment for learning difficult things and 'bringing it altogether'. Unfortunately, it was hard to gain more explanation from participants about the specifics of this need or what is going on in their minds at the time. However, it became apparent that several participants felt that they required a moment of calm for the "penny to drop" (Expert 5, Interview 1) or to " join the dots to understand a concept" (Case 7, Journal). The following interview sequence provided several reasons for the importance of calmness and confidence in his own ability for conceptual learning:

> Case 7: It was like I had this sense of calm where I was just like, all right, at the end I am going to understand it. I was just going through and the sense of calm of like, yes, all right, this makes sense.
>
> Interviewer: So, you were accepting what was coming to you, trusting.
>
> Case 7: Trusting my brain, yeah.

And later on, he described further how this state of calm could be conjured up as well:

> Yeah, everything seems important to you if you're not calm, and that's the thing, I think in that moment of time I was acting as if I already knew it but just forgot and was revising it. I think that's how I became calm.

He felt that this aided more efficient thinking:

> I'll be in that calm state of I already know this, and I think I'll know what I'll be looking for or be able to create stronger links, and disassociations, like, this is definitely not this. (Case 7, Interview 2)

This appears similar in some ways to diffuse thinking that was examined in the previous chapter. This sense of calm required a level of control to initiate and maintain but was valued, as it enabled integrative learning.

Collective ZPD for Troublesome Learning

In the previous chapter, peer learning and teaching was acknowledged as a useful instructional assistant. As peers are more readily available for studying support than teachers and experts, peer learning is frequently used for tackling conceptual struggle points. Kilgore (1999, p. 198) describes how this magnifies the ZPD to become a collaborative, "expanded" zone of learning for concepts or a specific practice. 'More capable' instructors are not necessary in this collective ZPD, so long as there is sufficient sociocultural diversity in the peer group to provide a variety of "understandings" for the "collective learning process" (Kilgore, 1999, p. 198). Student cases were open about how important these peer dialogues were for their learning, especially at their learning sticking points. A first-year student had already latched onto this as useful, "everyone says that if you can explain your understanding to someone else then that means you understand that and, like, I think that's very true" (Case 7, Interview 1). He confirmed this opinion at the end of the year by saying that peer study "forces you to go to that high level of understanding" (Case 7, Interview 2). Meanwhile, the fifth-year student appeared fluent in employing this strategy to work out when to give up and get help:

> I think when I get stuck, I get really jarred out of the – [flow]. … Well, usually I ask someone else about it, like, we have a group on Facebook where we all post questions or my study buddy and then like, it's their responsibility now. (Case 3, Interview 2)

Similarly, a second-year student found it helpful to resolve the problem together with peers:

> And then I asked my friend, his [understanding of the] concept is also different. So, we got into this discussion. And apparently although I think we didn't reach a consensus about that, but somehow, it's a bit clearer. I guess we had that discussion, so you know that you're trying to understand it. (Case 2, Interview 1)

In my research, there is substantial evidence of the usefulness of dialogue for learning with self, with peers, with instructors and with instructive resources; dialogue is a powerful source of instruction for these students.

6.2.3 Inner Struggle is Obligatory

In the end, despite seeking assistance externally, the conceptual struggle and expected understanding and transformation has to take place in the learner's mind, "intramentally" (Vygotsky, 1997, p. 106). Here the student's inner speech, cognitive functions and previous knowledge will determine her progress, how and whether transformation is finally achieved. A first-year student commented on how he actively aimed to manipulate this conceptual learning for physiological concepts:

> So whenever I come across something relating to disease I always try to build the concept in my brain regarding the normal function of that particular body system and then I try to basically join the dots together, trying to connect all the particular organs in that particular body system and then try and find points where things are going wrong…

Interestingly, he achieves this by using inner speech for making meaning:

> …and basically when I'm doing that I'm essentially talking to myself because then I'm analysing what I already know about the problem and then I start thinking about what is the new thing that I'm going to know about and then by talking to myself I'm trying to bring it all together so it's one whole new concept. (Case 1, Interview 2)

Knowing it was essential to bring these ideas together, he has a strategy for tackling each new topic and its concepts, with the aim of creating the whole. It is this transformation process that remains tantalisingly difficult to see clearly (from both the student and researcher perspective), so the step in the analysis was to target this using a deeper abductive examination.

6.3 GENERATING TRANSFORMATION

This topographical element of the learning journey marks the main aim of disciplinary learning – mastery as a transformative journey from the novice to competent learner, and for some, ultimately, disciplinary expert. For this analysis, the student case data were more revealing than the expert interview data. The case data were spread across the whole year as journal reflections, with the interviews at beginning and near the end. It was disquieting (as an educator) for me to hear how hard it was for students to clarify and evaluate their understanding. Students found it tougher than I expected to know when they have 'got' a concept, unless there was an associated emotional, transformative experience, or they were tested by teaching a peer, or attempted an exam question. They realised that if they can teach it or complete a problem-solving exercise easily, then this is an indicator of successful understanding. In addition, they could tell easily that they hadn't understood it before, once the concept had fully 'clicked'. Unsurprisingly, students within the liminal space or ZPD could feel when they were still uncertain and hadn't understood as yet, but often had no idea how far they were from 'getting it'. A first-year student had good insight into this. He explained in his second interview that he understood a concept related to screening, because he knew that:

> if it were concrete in my mind, I could look at it and I would immediately recall what it is without having to go through notes or even think about it quite a lot to kind of work it out in my mind. It would just be a more kind of natural process. (Case 7, Interview 2)

Yet, when considering the same concept earlier in the year, he said "although maybe there's something that I'm not getting about it that I don't even realise that I'm not understanding" (Case 7, Interview 1). At that earlier time, he was less certain how much he understood, suggesting that was still in the liminal space or on the edge of the threshold of understanding.

As mentioned previously, there was an inconsistency in identification of transformation of students compared to experts which was attributed to a variability of the learning experience and individual perception of these concepts. This is a known phenomenon in threshold concept literature (Baillie et al., 2013). In addition, identification of the threshold concepts appeared more difficult if the concepts were part of a network of concepts or part of an over-arching threshold concept. These overarching, synthesising threshold concepts provide the massive ontological perspective shift, as previously described in Kennedy's (1998, p. 487) "revelation" on learning statistics and being suddenly able "to make sense" of the "statistical world." This ontological shift seems to be most obvious when several concepts and minor threshold concepts come together to form this over-arching threshold concept. This corresponds with an often emotional and major transformative alteration in knowledge understanding and also disciplinary perspective that is irreversible and integrative.

Unfortunately, the irreversible and integrative nature of these transformations prevented participants from detailing their experience in full. Student cases agreed that after this ontological change there was a certain degree of forgetfulness and inability to conceive their previous lack of understanding. Interestingly, this was often related to emotional responses and experiences related to the learning. This apparently counterintuitive effect happens because, on crossing that threshold, the student loses the ability to be confused and although she may remember the struggle, confusion and discomfort of not understanding, often she can no longer see the path which she has taken, which may have been full of difficulty and re-iteration. The fifth-year student provided an example of this during her second interview, where she explained about using concept maps to understand a physiological pathway:

> Yeah, I remember the feeling of being really confused, but I think that I see things that way now, so even looking at my old notes, I have the perspective of these categories and these clear relationships. Like, I remember being really confused but if I looked at it again, I wouldn't have that, yeah, perspective. (Case 3, Interview 2)

Students also noted the irreversibility of this shift in change, something that they were quite relieved about as they did not have to go through the same degree of struggle again. A first-year student was very clear about how he felt in terms of when he fully understood a concept, in that it was became an effortless process to recognise when and how to employ the concept:

> Once you get the full picture, I don't ever forget it so it's like a skill in the sense that – you know, riding a bike or driving a car, once you've got this logic path in your head is – it's just there. (Case 8, Interview 1)

Another first-year student explained how his transformation in terms of understanding confidence intervals went hand in hand with the integration of associated concepts. It was this bringing together of concepts that made this conceptual process irreversible for him. Initially on meeting this concept he considered it simple, but it became "transformative in my learning." When applying the concept to examples "it opened a new avenue in my brain regarding this particular area. … allowed me to integrate a lot of different aspects of statistical tests, so the chi square and the t test" (Case 1, Interview 2).

In terms of theory, the irreversible, integrative TCF characteristics of threshold concept learning synergise well with the idea of the ZPD conceptual development movement across into the ZAD, which Vygotsky treated as a permanent layering of cognitive development and way of thinking. Surprisingly, students found that if they didn't use a newly understood concept immediately, this early understanding could be lost. For example, a student reflecting on his learning at the end of his first year, thought that he had understood a threshold concept in a medical science subject in the previous semester, but hadn't had occasion to think about it since. He felt like he had lost this understanding: "Yeah, and it was one of those irreversible things, at least for a term afterwards" (Case 6, Interview 1). This may well be because he had not been not fully post-transformational but was vacillating on the edge of the threshold. Additionally, he had not used this concept in practice, and so his learning lacked that necessary experiential element, the testing out a theory or concept by application, followed by concrete use and reflection as part of the natural cycle of learning (Kolb, 2015).

Overall, the student cases provided more detail than the experts regarding the ZPD-liminal space and transformational experiences, but their awareness of the process was variable. As previously discussed, the TCF especially has several more recent important publications espousing the theory and others that provide evidence to support this (Cousin, 2006b; Land, 2016; Rattray, 2016). From the Vygotskian perspective, *perezhivanie* provides useful insight. This can be described as the "living through" of a child's learning experiences and social environment that together determines how she will react to life's events (Vygotsky, 1994, p. 341). Michell (2016, p. 5) argues that this complex concept should not just be considered as emotional experience, but is "best understood, psychologically, as an intellectual gestalt reflecting the intellectualisation of perception and, ontologically, as an apperceptual organ of selection" of consciousness and personality "refracting" the child's individual social situation of development. Hence, the emotional experiences of conceptual development are "personality-specific" as *perezhivanie* develops differently for each child (Michell, 2016, p. 11). It also relates directly to "meaningful perception" and ontological change, suggesting that emotion and transformational development are closely and inherently linked (Vygotsky, 1987a, p. 190).

In examining the data, I was keen to examine this transformative aspect of the learning and have demonstrated that the students (and experts) were aware of making meaning and experiencing transformation within the learning environment of the medicine program. However, the framework as applied to the data does not fully explain the overwhelming emotions experienced by the students from the 'eureka' feeling to the feelings of being incredibly overwhelmed, frustrated and even angry at themselves. The initial abductive analysis that identified key conceptual elements, and the second analysis of the transformation experience, had not drilled down deep enough to investigate this fully. Hence, further examination of the data was undertaken to discover how participants viewed this struggle in Vygotskian and TCF terms. This section reports on these findings, providing: 1) evidence of higher mental functions maturing within the ZPD/liminal space, including conceptual understanding, ability to use the concept abstractly and consolidation of networks; 2) evidence of cultural imitation and collaboration; and 3) evidence of social ontogenesis as transformation.

6.3.1 Evidence of Maturation of Higher Mental Functions

Vygotsky defined the ZPD as the developmental moment where elementary mental functions of the child (perception, memory, attention, thinking and volition) are in the process of developing into their higher, culturally mediated forms; maturing but not yet in a fully mature form. This next step of the abductive analysis required the application of Vygotsky's theory of higher mental functions across the data. Vygotsky describes this perspective of the ZPD by using an analogy from nature to illustrate his belief that these "functions could be termed the 'buds' or 'flowers' of development rather than the 'fruits' of development” (Vygotsky, 1978, p. 42). This is taken to mean that the zone of actual development (ZAD) represents the child’s retrospective mental development; what they have learned previously and currently are conceptually capable of understanding in terms of knowledge and perspective. In contrast, the ZPD represents the child’s potential prospectively. This is the zone of learning where the child is capable of developing new and higher mental development with assistance (such as from a teacher), but they are not yet mature (Vygotsky, 1978). In Vygotskian terms the instruction acts as a to challenge to the child, aiming to lift them to the next level of the developmental process. Vygotsky was keen to advocate that the “only ‘good learning’ is that which is an advance in development” (Vygotsky, 1978, p. 89). The higher mental functions used and gained in the ZPD include the critical, transformative function of *abstract thinking.* For Vygotsky, abstract thinking was vital for the later stages of a child’s cognitive development, notably in adolescence. Further, he believed that it typifies the adult way of thinking and cognition, in strong contrast to early childhood’s thinking as straightforward recall (Vygotsky, 1978). This way of thinking is comparable to Dewey’s (1910a, pp. 135–138) idea of “abstract” thinking, which he compared to “concrete” thinking. Dewey explains that being able to grasp the indirect meanings of words is an abstract achievement: “The meanings of some terms and things, however, are grasped only by first calling to mind more familiar things and then tracing out connections between them and what we do not understand” (Dewey, 1910a, p. 136). In contrast, Mezirow’s understanding is different as he stated that abstract thought is part of the basic learning needed for children to “think autonomously,” and goes on to state that thinking “hypothetically” and becoming critically reflective of what they “read, see and hear” are the next stage of development in adolescence (Mezirow, 1997, p. 9). Into adulthood, the skills of awareness, recognition of “collective frames of reference” and the ability to work responsibly and effectively with others comes to the fore (Mezirow, 1997, p. 9). Beyond basic adult development, Perkins and Salomon believed that deliberate, mindful abstraction is the key to “high road transfer,” which is the ability to apply skills and knowledge by “reflective thought in abstracting from one context and seeking connections with others” (Perkins & Salomon, 1992, p. 25-26). They saw this as an essential adult higher cognitive function for encouraging beneficial academic thought, and as a way to develop students as more creative and critical thinkers and doers (Perkins & Salomon, 1992, p. 23). For the purposes of this research, abstract thinking was investigated along Vygotskian lines, as it was relevant to the second thesis research question regarding critical thinking in conceptual learning and the making meaning of new academic concepts.

Critical Thinking for Transformation

Identifying and analysing 'higher mental functions' within interview and journal data was not easy, but there were key areas where it was possible to hear how students reflected the change in their thinking and approach to learning. For example, all of the students seemed aware from an early stage of the medical program that their learning strategies used for their high school leaving examinations, would not work well in undergraduate Medicine. They described (using various different examples) how rote-learning and surface learning sufficed at times for these exams. Also, they learned very quickly that for a university degree of this complexity, full understanding of the content and the ability to use this knowledge is necessary in becoming a practising doctor. One student explained how he had realised that he would have to change his current learning strategy (a remnant of his HSC years) completely to keep up with the fast pace of the difficult conceptual learning during the first year at medical school:

> *in the HSC, there are clearly defined, specific syllabus dot points which you have to learn and memorise, whereas in Medicine you are required to learn and UNDERSTAND concepts. Furthermore, there is a significant increase in content taught in Medicine in a single course compared to the HSC. In the HSC, you can get away with learning isolated dot points, whereas in Medicine you must make connections between content.* (Case 7, Journal, emphasis in original)

One study technique that he used was discovered in a 'how to learn' resource found online, which he describes here as "repetition," but in other examples he demonstrates that this repetition is actually repeated exposure to examples and the application of the not-quite understood knowledge and concept. Applying this practice finally enabled the crossing of the conceptual threshold for him:

> *analysis and appraisal of my performance and making a final judgement. ...* ***Repeated testing much better than repeated studying – very important!!!!!!*** *Feedback enhances learning, but even testing without feedback is beneficial. Delayed feedback is best – results in spaced representation of learning content. Active recall is a significantly more effective learning strategy than passive restudying of facts.* (Case 7, Journal, emphasis in original)

Interestingly, in this journal entry the student identifies the critical thinking skills (analysis, appraisal, judgement) that he was applying to his own performance, providing self-feedback as part of this deeper learning. With good insight, he was aware that his strategy needed to be deep learning for full understanding, as he clarifies further here:

> *Going over concepts repetitively helps you to be able to apply the concept – it 'drums it into your head'. However, there is probably an argument to be made that learning a concept repetitively doesn't help you to understand it – it just means that you rote memorise how to apply it.* (Case 7, Journal)

An alternative method used by these students to encourage deeper learning was taking a holistic approach, rather than focusing on one topic or concept. In fact, it was surprising that by the end of their first year, the novice students already understood that a more rounded approach to learning could be productive and elicit a deeper understanding, with transformational change: "[I] think that's the point of developing that kind of holistic understanding rather than just looking at a specific system and saying this is what happens" (Case 7, Interview 2). The maturity of this approach so soon after starting the medicine program is not unusual and is generally thought to be induced by the fast learning pace and high volume of conceptual learning that has to be achieved in the short length (7 weeks) of each integrated Phase 1 course.

Trying to discover the factors that enable this understanding of concepts through deeper learning was not easy. In analysing the data, abstraction as a critical thinking skill was specifically mentioned by three of the students in relation to learning mathematical formulations (especially in mathematics and physics). Following application of abstraction, other critical thinking skills were employed to build the conceptual 'image' back together and make it whole and understood. So, following on from the initial three critical thinking steps to break the concepts down, the three next critical thinking steps in the transformative process are for rebuilding of the concepts using abstraction, synthesis and integration, as detailed below.

Step 4: Abstraction

This critical thinking strategy seems to be employed directly following the previously described stages that 'unpick' the concept using simplification, clarification and/or categorisation process. Once the complex concept or idea is broken down to simpler elements thinking by abstraction can take place more easily. The simplification allows the underlying principles and concept linkages to be more easily 'seen' and therefore be identified, acknowledged and used to create a whole. However, this step can produce a sense of confusion and lead to panic as the whole concept is deconstructed and being viewed with the aim of rebuilt. “You’re just, kind of, lost in that abstract world of information that you’re trying to put together” (Case 3, Interview 2). One way of visualising the conceptual systematisation was provided by a first-year student during the focus group discussion. He described coping with the abstract nature of conceptual construction of a concept as similar to having the:

> wooden frames of a house but you don’t know exactly what it’s going to look like … but then as you develop on and on, and on, you know, a window sill, a door here, and you’re finding it visually. (Student 1, Focus group)

He further expanded on this house-building metaphor later, saying it is like having a framework of a house that you have to build up from basic materials to discover what shape it will be:

> sometimes you don’t get the concept of it first, then you come back and revisit it, and it makes sense. I think that has something to do with --- how you see the ultimate framework or the concept, like – like the framework of the house, like, you can’t see it as a hut (I’m going through my metaphor) but then, like, when you come back you can – you can see teepee shape that forms the top of the hut… (Student 1, Focus group)

Abstraction enables visualisation of the whole, and reconstruction is next step, using synthesis and integration to build the concept back into an understandable configuration for the learner.

Step 5: Synthesis and Integration

This vital step builds the concept back up, synthesising and integrating the knowledge to recreate the threshold concepts in a way that is understandable for the learner. Student cases provided useful insight here. This process is remembered as a ‘eureka’ moment for some but less emotionally for others. In Vygotskian and critical thinking terms, the students are making meaning of the concept(s), and at the same time clarifying, understanding and integrating to recreate the whole. This is a key point in Vygotskian systematisation of concepts terms and also for the final threshold crossing in the TCF liminal space. If successful, this can be transformative from both theoretical perspectives.

Sometimes, a simple resource can assist this integration. For example, a first-year student reflected in his journal mentioned a table that I use to teach the differences between three of the most common, basic statistical tests. He thought this was:

great as it allowed me to confirm my understanding of the tests and further sharpen the border between tests and when to use them. Perhaps can be considered as an integrative concept. (Case 6, Journal)

The table was helpful for this student, but, in contrast, another student needed to go through all of the written examples of the different tests that were provided as well, in order to gain full understanding.

So, where conceptual distinctions are apparent within the learning topic, clarifying this directly and succinctly for the students is helpful. For example, biochemical, physiological and pathological cascade relationships and feedback loops were identified by students as key areas of integrative learning where concept mapping and clear diagrams were helpful. In some scenario group and tutorial sessions, the students create their own concept maps or fill in prepared diagrams using online tools. These were identified as effective ways to learn how the various concepts fitted together to create the whole scientific conceptual understanding and to assist with transformative threshold concept learning. Interestingly, some students were active in creating their own diagrams and concept maps and found that this was a more profound learning experience than reading a ready-prepared or published resource.

Several students expressed a need to have an established idea of the relationships between the concepts to be able to create a network that can 'click' the concepts into place correctly. Howe (1996) describes this as an abstract to a concrete move, and from a TCF perspective this is, in fact, one of the main threshold concept process characteristics, namely, integration. A good example of this came from the third-year student, talking about how the visualisation of the links in renal pathology was "poorly taught," with not enough time spent on it. To compensate, she said that she did a lot of "self-learning" and drew "many diagrams" that had branches showing the different causes of acute and chronic renal failure and the symptoms of each pathology. It was only then that it all fitted together for her, and she had a transformational 'eureka moment' when she: *"stepped back and looked at the diagram - finally all the pieces fitted together"* (Case 5, Journal). For a first-year student, this integration was focused best in certain systems, which is a form of categorisation (another critical thinking skill):

I have found it useful to study various medical concepts by integrating the physiology of various body systems. I believe that this helps me get a good grasp of the concepts. (Case 1, Journal)

Also, this worked for another student, who said, whilst reflecting back on his first year of study:

> And I think it also helped looking at, as a kind of system based. I mean, I know the UNSW Medicine program is quite innovative in how it structures its program and that's a very good thing. But I think for the cardiovascular system we did look at it as a kind of system. And I think that did help integrating a few different concepts. (Case 7, Interview 2)

He sounded genuinely surprised that he had finally appreciated how his learning fitted with the curricular structure of the program.

Another first-year student describes he feels that he is "strengthening" the web, adding more layers to it" by reiteration, revisiting and applying the concepts:

> So, by revisiting you have a great opportunity to explore the more peripheral parts that are, I suppose, less important but the thing is that by visiting these side links, not only do you add more knowledge, so to speak, or skills, they re-interconnect back again to the original main concept and that reinforces that main concept and even generalises it. (Case 8, Interview 1)

It is as if he imagines this as travelling through a place that has various stops that he can explore more each time that he visits. This example provides a high-level reflection on the process of this student's conceptual learning. It touches on the interconnectedness of his learning and the idea that when a main concept is understood fully in relation to its related concepts, this allows it to be generalised to other contexts. This student goes on to explain how physics formulae can be simplified and just accepted for high school level learning, but later, when revisited these have to be taken to a higher level. He said, "in a uni course or a text book you go, oh, it's that bit, I'm enlightened" (Case 8, Interview 1). During those further "rounds" of exposure he found he could learn more as he had the ability at this more mature level to layer this incremental of learning on top of previous learning more effectively. This echoes the principle of development of the mental functions within the ZPD and shows how the common teaching method of scaffolding can work for this type of learning. In addition, the travelling analogy that this student uses to describe this learning journey, with its revisiting, re-exposure cycle echoes the ZPD and liminal space as reiterative learning experiences. This analysis data confirms that a key element of the conceptual struggle encountered in learning a threshold concept is the piecing together of other concepts to integrate into networks. Indeed, several students mentioned how important it is for these concepts and processes to be presented logically and with adequate explanation early on in their learning. The same student explained this best when he described conceptual learning as a web and realised that:

> You have to do it the right way. I think, introduce this whole thing in the right direction and then it eases in, but if you're really fragmented or if you go there without explaining another concept it's much harder. (Case 8, Interview 1)

Clearly setting out conceptual flows, relationships and contrasts appears to be an important step towards assisting student learning in medicine.

Step 6: Conceptual Knowledge and Perspective into Practice

The final strategy uncovered within the data refers to the final (sixth) step that follows transformation. This is the post-liminal mode in TCF, where the concretisation and application of knowledge skills needs to happen for it to become part of their practice. From the Vygotskian point of view, the learner is in a new ZAD, and their nascent, fresh ontological perspective needs to be tested out and used for these new understandings (meaning-makings) to be embedded fully with their previous learning. Certain actions can lead the student beyond basic conceptual understanding to practising a new way of thinking and practice. From the medicine program perspective, it appears that progress in conceptual learning (within both ZPD/liminal and ZAD/post-liminal spaces) is facilitated when students see the application of the concept modelled in real situations and then practice it themselves, reminiscent of the experiential learning of the Kolb cycle (2015).

For example, authentic and/or complex problem-solving activities can actively or passively trigger the firm establishment of a transformed concept. Students spoke and reflected on using problem-solving approaches alongside other critical thinking strategies, including decision-making and making judgements. These are all higher-level, applied critical thinking approaches that apply nearly or already understood concepts into real or authentic practice situations to uncover any uncertainties or misunderstandings. Conceptual challenges such as short- or long-style examination questions, complex exercise problems or scenario-based questions can bring these approaches into play. For example, this learning was stimulated for the student cases by using various strategies, such as: clinical scenario cases; the interpretation of real statistical results and application of the findings to a scenario patient; critical appraisal of research (especially around bias and validity); and clinical application of results (clinical significance).

Another example of the importance of putting conceptual learning into practice was when students learnt about the concepts of clinical and statistical significance and found this revelatory. They found that these concepts only clicked fully into place when they were presented with written examples and diagrams that explained the concepts' meanings beyond the basic definitions, whilst also accentuating the difference between them. The following example is one of several from different student cases who volunteered this information:

> So those are actually the basic - the methodologies by which you can perform statistical testing and then you have to translate your results into either statistical significance or clinical significance. So basically, going through those tutorials had me bring it all together. (Case 1, Interview 2)

What is fascinating about these students' reflections on their learning, is that the ontological change shines through. It is possible to almost feel the excitement of the students as a more statistical way of thinking came into focus for them. What assisted another first-year student's learning was working backwards through a worked example:

> …just to push through as much as I can, yeah, grinding through exercises but also reflecting on the solutions because reading the solutions forwards most of the time don't make sense but if you read the solutions backwards it makes sense. And you have to use experience you've gained from every question you've done. You reflect on the questions you've done and you're, okay, so now I have the foresight and building up this foresight – well, actually, the hindsight really. We're building up this hindsight … so you have the foresight in the future to use this experience. (Case 8, Interview 1)

This student had discovered a useful studying technique for working out mathematical and statistical concepts, but he added that this was a very challenging way of learning.

There was an emphasis within the data on the theme of seeking feedback on practice for extension and consolidation of learning. Student cases spoke of actively seeking feedback and looking for problem-solving exercises as these positively assisted with their learning in terms of the iterative practice of applying a newly learned concept. Also, this feedback directly showed them when and what they did not understand, which in turn meant that they could seek assistance or look for resources for further self-teaching. There were several examples of learning activities that helped, including: the online QMP learning activity resources (e.g. the adaptive tutorials); problem-solving exercises stimulating transformation; exam questions and formative quizzes as self-testing, (especially good for showing when a concept was not understood); and verbal or written feedback sought directly from teacher, peer, further assessments or quizzes.

In addition, several students found that examination questions, both formative and summative were useful for conceptual learning. Initially, for one first-year student a practice exam question was useful as it made him reconsider the whole anatomy and physiology centering around pathology of the mitral valve in the heart. In fact, he could remember a great amount of detail about this one exam question from earlier in the year. This suggests that this was a deep learning experience, which is contrary to the commonly held belief that examinations are not useful for learning, only for testing. He commented further on his experience of rote-learning for this course exam and reflected that it was the clinical scenario used in the exam question that was helpful, as it forced him to think of the various medical science parts separately and then put them together to provide an answer. Essentially, the scenario was useful for linking the concepts up. Later he said that rote-learning of isolated facts was not useful "as it's not linked to anything in my mind I would have forgotten" it quickly. In contrast, when he studied and learned whole scenarios and cases, this meant that he was "able to link something in your mind to an actual scenario; it's a very powerful method of learning" (Case 7, Interview 2). In a later comment regarding the learning of statistical concepts, he reemphasised this point about linking concepts using clinical examples: "whenever you're able to link it to an example, you – yeah, I think it facilitates memorising or long-term retention is a lot better" (Case 7, Interview 2).

As detailed in the previous chapter, all student cases provided clear, memorable examples of scenario or case-based learning activities or assessments that assisted directly in the integration of conceptual understanding, both for bioscience and clinical study and in their EBP and biostatistics learning. This is a significant finding and could provide a useful way forward for developing learning activities and assessments based around the major conceptual elements. These three final critical thinking steps for transformative learning are depicted in the Figure 6.4 below.

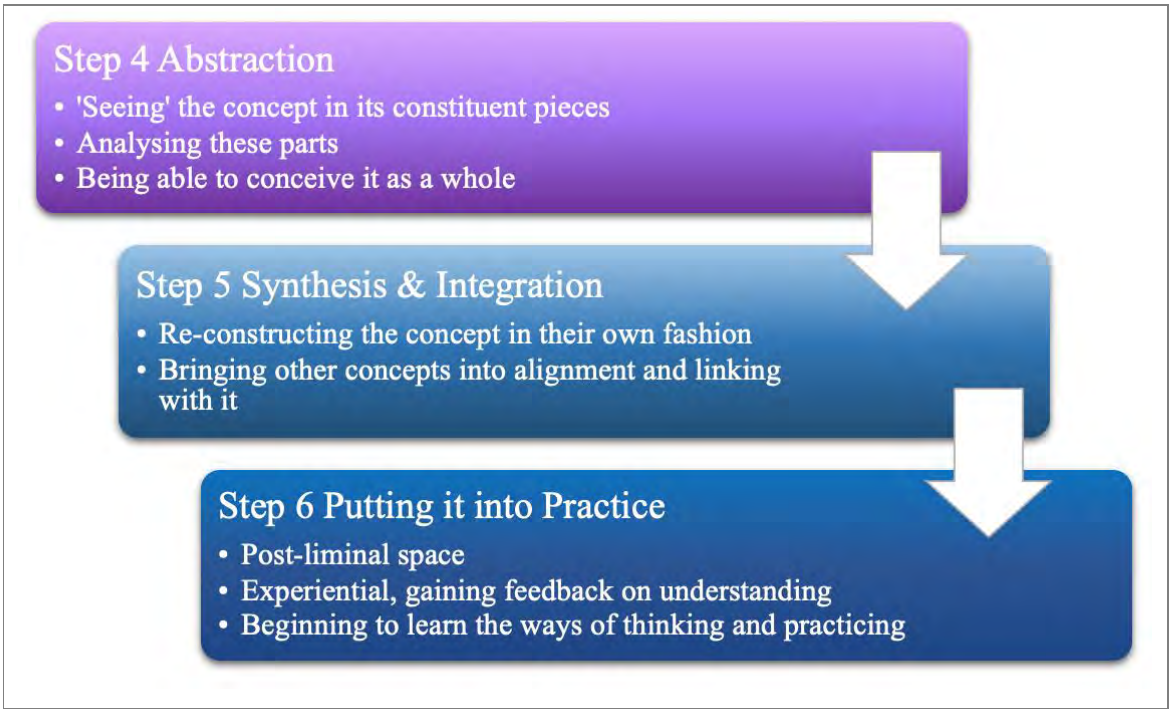

Figure 6.4 The three liminal critical thinking steps for transformation

In summary, seeking challenging situations, problem-based scenarios and active feedback on practice has a positive impact on both the ignition and substantiation of transformation for EBP, scientific and clinical concept understanding, especially in learning the ways of putting these into practice. This process assists the creation of a systemisation of conceptual networks by testing, challenging and provoking the conceptual understanding during a more authentic application of the concept.

Implications for Learning and Teaching

Students can see the 'whole picture' of their conceptual learning process, often in a very individual, visual or metaphorical way. They recognised that this conceptual journey involved iterative incursions into conceptual struggle and appreciated assistance from the learning activities that assisted those incursions and the gradual building of knowledge. However, encouraging them to talk about higher mental functions was not so easy, especially regarding critical thinking skills such as abstraction, for navigation of the liminal space and assisting in the ZPD instruction. This section of evidence adds to previously presented evidence to show that students were aware of the learning approaches that fostered higher mental functions (such as scaffolding and presentation of clear pathways for the conceptual learning journey). It also exposed strategies that were less good for conceptual learning, including when learning objectives are not clear or when definitions were poorly explained. Also, students were alert to the conditions that assisted their learning and the barriers that hindered it.

Gaining a clear understanding of the key conceptual networks appeared vital for student progression in EBP and statistics, so further analysis was carried out to find specific learning approaches and examples that assisted students in reaching this point. Many, quite varied learning approaches were used by students, including written/textual, visual, mathematical, social and auditory. As mentioned in Chapter Five, the commonest were the written/textual (including inner speech/dialogue) and visual. However, it was rare for a student to utilise just one approach; these were employed mostly in combination, although occasionally individual approaches were chosen for specific learning tasks. Further, these approaches were used in conjunction with inner experiences such as inner speech as a teaching aid, as discussed in the previous chapter. An important point here is that the choice of learning activities used by students was often influenced by the teaching approaches and curricular learning activities and assessments provided by their current (or sometimes previous) courses. Students reflected that learning activities that encouraged the application of the bioscience to the clinical, or of biostatistics to a patient case were more helpful than those without a scenario. For one first-year student, real-life experiences worked best for facilitation of integration and concretion of conceptual understandings. He said "I think it is a big thing of application and forcing you to join the dots. I mean I am particularly thinking of these pathology cases that we had" (Case 7, Interview 2). He went on to describe in detail a case of a patient who was an intravenous drug user and the pathology that was involved in their assessment, diagnosis and treatment. He found that this scenario as used in the pathology teaching worked well as it clearly showed the links between the case and the pathology for him to follow, as "we saw lots of different cases but … – when you always see a relevance of why you're doing something, it just makes it so much more important and so much more memorable" (Case 7, Interview 2).

Later, this student talked about another useful clinical learning experience for myocardial infarct (heart attack) which had been learned during the course as medical science. This effective learning moment occurred when he was part of a group of students on a clinical visit to hospital. The tutor group was present on the ward as a patient experienced an infarct. Their tutor went through the whole process with them afterwards (as he was tied up with sorting out the patient at the time of the event) and for the student this immediate relevance and real-time experience of the learning made the difference to his understanding of the bioscience that he had been taught:

> It was like, 'wow', we just learnt this yesterday in a lecture but now we're seeing it in hospital, so it's all relevant. So, I think whenever you can see the relevance of something and link it to an example of why it's important, it is very powerful. (Case 7, Interview 2)

These most powerful learning moments occur in the clinical environment, in the real-life situation. This is important to remember as time, on the wards, with patients is being reduced by pressures such as there are less patients staying long periods in hospital wards, there are larger tutorial sizes, stressed hospital systems and a change in attitudes to clinical teaching away from its voluntary status in medical practice. My finding suggests that we need to consider other ways to provide these authentic learning experiences. Simulation (Kneebone, Scott, Darzi, & Horrocks, 2004), team-based learning (Michaelsen et al., 2014) and scenario-based learning (Balasooriya et al., 2009) are providing useful options, but there is a need to ensure that they work effectively for transformation and don't limit conceptual learning outcomes to rote-learned knowledge or only achieving partial transformation.

Finally, there was acknowledgement by students (and experts) that this type of learning is hard work. Several students admitted to doing their own research to discover useful studying methods and techniques and found some of these helpful. Overall, it seemed as if they preferred to find their own way to studying rather than following medical program suggestions. However, there seems to be room here for curriculum redesign to assist with learning approaches and for more resources to be made available to assist students to find and use the most appropriate study techniques and strategies for their individual learning. For example, concept-mapping is being used successfully in dentistry and other health professional training (e.g. Kinchin et al., 2011).

Transformation and Higher Mental Functions

According to the TCF, the struggle of transformative learning denotes a shift to higher mental functions. Interestingly, emotional responses to this process were universal across the case studies. All students experienced moments of revelation that were uplifting and contrasting moments of despair and anxiety that could lead to disengagement from learning and impedance to learning due to feelings of hopelessness. What was clear in the analysis was that this process of conceptual learning can take a substantial time. Even the most senior student in the case study admitted that she was still struggling occasionally with previously learned over-arching concepts and the relevant sub-concepts, despite being five years into her medical degree. Indeed, it would have been useful to talk with more higher-level students or post-graduate students to see when they finally felt confident in their application of these concepts. From the various personal learning stories told by the experts in the interviews, this learning can take years to achieve and establish fully. Even then, there can still be momentary lapses of confidence and ability where they are less certain of their footing, such as disciplinary overlapping areas, in topics that are not fully in their expertise area, or where the conceptual understanding is forgotten due to neglect and their conceptual memory of it falters.

In conclusion, developing the higher-level critical thinking skills including abstraction and problem-solving appears to be a crucial, inherent element of the process to improvement in mental functions that are expected within the ZPD/liminal space. Indeed, it is so ingrained in this transformation process that it is hard to unravel the skills being used and gained in the developmental process from the data available here. In theory, the transformation of conceptual learning uncovered here for biostatistics and EBP could be improved by reinforcing the critical thinking skills of students and guiding students directly to how these could be used in their conceptual learning. So, this was subject to a further abductive analysis and is reported later in this chapter. The other key element of this process is the student's approach to learning. From the analysis, it seemed most important for a learner to have the right learning approach, "deep-achieving" rather than "surface-achieving" learning (Biggs, 1988, pp. 129–130). Fortunately, my data indicates that the students naturally favoured a deep learning approach with its intrinsic critical thinking processes; they instinctively knew that it works better in the long run for conceptual transformation.

6.3.2 Evidence of Cultural Imitation

The second perspective of the ZPD involved Vygotsky's focus on culture as the key source of human development. This led him to advance the notion of *imitation* as the fundamental mechanism of human development, which was a radical idea at a time when only independent action was thought to denote progress in learning. Imitation happens through cultural interaction, the learner creating a "copy from the social" (Vygotsky, 1997, p. 106). For Vygotsky, the learner's imitation of the knowledge reflected that they had "a certain understanding of the situation" (Vygotsky, 1999, p. 95); an ability to copy a conceptual process showed the ability to develop that conceptual understanding. From a threshold concept framework (TCF) perspective, imitation is vital for the crossing of the liminal space. Meyer and Land (2005, p. 377) called this *mimicry* but consider this to be more than surface-learning or a pretence of understanding. Rather, mimicry is a "serious attempt to come to terms with conceptual difficulty" (Meyer & Land, 2005, p. 383).

In summary, conceptual understanding within the ZPD/liminal space, involves a degree of creative intellectual activity, where the child learner develops his or her "intellectual capacities through imitation and instruction" (Vygotsky, 1987b, p. 210) and hence is capable of learning new things. Vygotsky stressed that imitation was more than a mindless mimicking of knowledge; that it was in fact an active understanding and approximation of the available cultural models as acquired and re-expressed by the child (Vygotsky, 1998c, p. 202). This "intelligent imitation" with its "sphere of imitation" and "zone of imitative potential" became the conceptual template for Vygotsky's ZPD; the learning moment or location where the person, their mind and their culture intersect, and when and where the learner's mental functions can be raised above their actual level of development (Vygotsky, 1998c, pp. 201–202). Zaretskii (2009) and other followers of Vygotsky are keen to show that imitation is not just a repetition of what the instructor says or does, but is used in a much broader sense using the term "collaboration," in that the child might gain the knowledge or concepts from the adult, and simultaneously she learns the "way that particular adult does something" (Zaretskii, 2009, p. 80). This correlates well with the fundamental idea of the TCF disciplinary way of thinking, defining their "academic territories" (Meyer & Land, 2003, p. 5), and with Perkins' idea of the disciplinary character or "episteme," which results in a need for the novice in the discipline to be initiated into an "underlying game" (Perkins, 2006, p.41-42).

At this point I dare to use a Star Trek analogy concerning the Borg, a fictional alien race who seek to assimilate all species it considers useful into its collective or "hive" (Brkich & Barko, 2012, p. 793). This Borg assimilation of other species fulfills their fundamental priority which is the achievement of perfection (Brkich & Barko, 2012, p. 790). When a being is assimilated into the collective, the Borg don't just inculcate their recruits with knowledge and skills but plug them directly into the hive mind so that they have the same way of thinking as the rest of collective (Pichler, 2015). Obviously, the process of learning in higher education assimilation is less authoritarian and absolute in nature. The learner is not plugged into a 'hive mind', thinking as a consciousness at one with all academics in the discipline. However, there is a degree of like-mindedness and collective mentality accepted in disciplinary academia that can drown out the individual way of thinking. Overall, conceptual, disciplinary learning is voluntary, not forced, but the perception changes are key to both of these imitative processes. The Borg imitate the knowledge and also the perspectives and viewpoints of the hive mind, like a novice learner undergoes an acculturation process initiated by her teacher to a new disciplinary way of thinking, not just a taking on board of knowledge. Taking the analogy further, the Borg's goal to reach perfection is not so far from the view of experts regarding their own disciplinary knowledge and way of thinking, in that disciplinary experts often fail to see other points of view and positions, living and thinking through their disciplinary lens as the one true way (Becher & Trowler, 2001).

Within the current medicine program, the teacher, the tutor, the more competent or expert student, and the medical scientist are collaborators in the students' learning in pre-clinical teaching. Instructors and co-learners figured extensively in the student case reflections and interviews, with experts also noting their importance and role. However, staff at the clinical sites were deemed even more vital, as they played the key collaborative instructor roles for that essential transition to a clinical practitioner. Clinicians, nurses and other health professionals play a lead role, but students also realised and acknowledged the central role of patients in their clinical learning (Nestel & Bentley, 2011). As shown above, some of the most powerful learning experiences were within the clinical environment, and all included patients providing learning stimulus and useful feedback. My findings confirm that imitation as collaboration with clinical teachers (and I include patients in this group) is essential for students' conceptual transformation to the more expert ways of thinking and practising.

Implications for Learning and Teaching

Using my Vygotsky-TCF framework, imitation and collaboration in conceptual learning have been shown to promote a disciplinary thinking as practice. This was shown by the learner as a certain degree of 'creativity' beyond their current level. Surprisingly, novice students showed a basic understanding that they needed to change their way of thinking to think medically, or like a statistician or like a researcher, depending on the discipline that they were learning. Later, this became holistic in scope as they were exposed to more clinical environments and clinical instruction, and it became their main goal to think and act like a clinician. Indeed, students realised that they have to learn many different perspectives to be a doctor – e.g. multiple medical science disciplines, statistics, EBP, clinical approaches, epidemiology and so on – and that it was vital to bring this all together for their clinical practice. However, they felt that this was overwhelming at times. As discussed in Chapter Four, this practitioner awareness was considered the main expected outcome for all students by the expert clinicians in the study, and is represented as an over-arching, transformational EBP-clinical perspective. The experts appreciate that this is difficult transformation and advocate a mentoring approach which is, in practice, quite hard to achieve with the current curricular design of short practicum rotations and crowded teaching hospital environments and high student to teacher ratios.

Obviously, teachers can't plug their students into a network to feed them understanding directly into their brain like the Borg (not yet anyway). So, imitation needs to be nurtured as individually as possible and innovative educational development could assist by building in scaffolded learning and support into relevant learning activities across the curricula.

6.3.3 Evidence of Social Ontogenesis as Transformation

Vygotsky's third perspective of the ZPD extends the imitation frame to focus on the *inter-mental* to *intra-mental* processes or in modern day terminology, the social to individual. It also explains the influences that construct the ZPD as a zone of social ontogenesis. This perspective endorses a central principle of Vygotsky's work (1997, p. 106), his *general genetic law of cultural development*, as outlined below:

> every function in the cultural development of the child appears on the stage twice, in two planes, first the social, then the psychological, first between people as an inter-mental category, then within the child as an intramental category. This pertains equally to voluntary attention, to logical memory, to the formation of concepts, and to the development of will.

Essentially, in this perspective of the ZPD, even the intellectual faculties we typically regard as an individual's capabilities are deemed to be ultimately manifestations of cultural formations produced through social interaction, i.e. socialisation with significant others.

Key to this social interaction are the adult-child and expert-novice relationships, which form the cultural agency and means of cultural transmission for the learning. These are fundamentally instructional relationships and, according to Vygotsky, are a vital means for the cultural shaping and transformation of the encultured individual in society. In his only explicit definition of the ZPD, Vygotsky indicates how collaboration within the ZPD, that is, problem-solving interaction between necessarily more capable others, lies at the heart of this cultural transmission and intellectual development. The ZPD is:

> the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1987b, p. 209)

Thus, he explained that the ZPD is a dynamic, cultural field created by a cooperative problem-solving interaction between the learner and the instructor (or knowledgeable peers) that indexes an individual's new and assisted learning and development. Therefore, in Vygotsky's model, in contrast to spontaneous concepts learned through everyday social interaction, instruction has a catalytic role in the learning of new academic concepts. So, intellectual development arising from academic concepts is dependent on collaborative learning with instructors or more learned peers (Chaiklin, 2003; Kozulin & Presseisen, 1995). Such collaborative learning essentially occurs through disciplinary discourse, either dialogically, through "thinking together'" or through an internal dialogue of "solo thinking" (Wells, 2007, p. 249), using the inner voice as an instructive way of thinking, as discussed in the previous chapter. Instruction according to Vygotsky is not didactic or free-learning but is an active guidance by the teacher in a "true collaboration" with the learner (Howe, 1996, p. 38). This corresponds to research within the TCF literature which tends towards a constructivist approach for its research and for the teaching of transformational concepts (Perkins, 2006). This resonates with previous research on statistical learning, which advocates that students should be active partners in their learning, connecting new knowledge and concepts with what they already know and believe, in order to construct their own understanding and meanings of the disciplinary field (Garfield & Ben-Zvi, 2007).

Collaboration with Expert Teachers, Tutors and Peers

Evidence from student cases reflecting on their learning in class and in tutorials was plentiful across all cases, was mentioned within the focus group and was acknowledged as a key learning technique by the experts. Evidence was shown in Chapter Five that described the effective use of peer learning and study groups by students for conceptual learning. Peer discussion in ethics tutorials (with expert guiding the discussion) was also mentioned as initiating deep learning when students were open to the conceptual struggles involved. In fact, peer-learning plays a large part of the formal and informal studying at UNSW, encouraged by a vertical integration of year cohorts in Phase 1, with first- and second-year students being taught together for the whole of semester 2 each year (Scicluna et al., 2015). However, expert discussions were found to be especially helpful by students if the quality of this input was high. The third-year student was keen to seek expert opinions and hear other people's discussions on difficult topics. A first-year student was sceptical about less good teacher input in terms of gauging the student conceptual level correctly, considering that having the knowledge presented in the correct order was very important (Case 8, Interview 1). At the same time students appreciate that teaching and helping to 'making sense' for the learner is not an easy task. In his own teaching, this student found that it might be clear in his own mind, but communicating this to his own students (as a high school tutor) was not as easy:

> I find it really hard to make all those connections in the right order because the problem is if you have all these mini concepts everywhere, people get lost. They're, like, 'Argh, you're talking about this here and then five minutes later you're talking about that and it doesn't fit together,' but in my head, obviously it all fits together, all right, it's this being aware that – it's all there, right? (Case 8, Interview 1)

This student's appreciation that teaching is difficult reflects the post-liminal state of irreversibility for the TCF and from the Vygotskian perspective. Also, it acknowledges that the teacher's ZFD is a step further away from the ZPD so that instructing the learner involves careful thought and preparation with reflection back to what might not be understood by the learner.

Theoretical Considerations

The main aim of teaching should be to assist the learner in constructing their own system of conceptual knowledge with the assistance of the instructor, interactive learning activities, and opportunities for peer and self-reflection. In essence, a learning principle and the aim of teaching should maximise the dialectic interaction for conceptual systematisation. In terms of supporting students, there is a need to identify and teach to the key concepts of a subject. This practice should include identifying and examining both threshold (transformational) and non-threshold concepts, as well as the basic principles and definitions. This concurs with most current teaching practice approaches and the TCF. How to teach this is another matter and will be addressed fully later. Here, findings from the student case study series emphasise that students need to be able to identify what they do, and what they do not understand. It was an important finding that students recognised the challenges that quizzes, questions, problems, scenarios, practical classes, both virtual and real learning situations afforded them in terms of evaluating their learning and in aiding transformation. The need to support students during this emotional, mentally challenging process is vital. Otherwise, it is too easy for students to default back to the easier, faster and less draining modes of pure surface learning, definition learning, and rote-learning, which medical students are known to be very skilled at (Biggs, 1988). It is clear also that students understand that they have a choice to try to grasp a concept, or not to try. Hence engagement and relevance are very important in the teaching of these troublesome topics.

One further aid to student understanding is the provision of adequate time for learning and transformation to occur. Students and experts throughout this study recognised that time for cogitation, repetition and exposure to relevant content, scenarios, and examples is vital to maximise the opportunities for conceptual synthesis and systematisation. This transformative process involves deep learning approaches that take time and emotional and mental energy. Most educational approaches emphasise organisation of student time (Biggs, 1988), but my findings suggest that allowing adequate gaps between conceptual learning journeys and providing a comfortable learning environment should be an essential element of curricular design.

In summary, students tend to opt to take the easy route unless they are assisted to take the deeper, harder route to full understanding. Often this happens naturally when they realise that they have not understood, or they fail an exam question or exam topic. The effective ways of learning are myriad, and each individual student has their own battery of learning approaches and strategies, including critical thinking skills and dialogue and inner voice methods to gain traction into these tricky concepts. Therefore, instruction and guidance are key to student success. For complex, concept-heavy and networked topics it is important to provide a clear outline of the expected conceptual journey that lies ahead for students, to assist self-study during the inevitable internal struggle to come.

6.4 FROM NOVICE TO EXPERT

The actual transformation process was easier to examine in terms of expertise as there appears to be different expertise phases in the transformation process. Firstly, there is the 'getting it' experience – the light bulb moment. This is followed by the application and problem-solving phase where applying the concept to a problem or similar process concretes the understanding. At this point the learner can say that they comprehend this concept and should be able to explain it to others. Beyond this lies the expertise phase of applying the concept(s) and adding to knowledge and improving skills – the honing of skills and knowledge for best clinical practice. The one student who did not follow-up his first interview with any reflective journals, gave one of the best descriptions of this towards the end of his only interview at the beginning of his first year in medicine:

> It's revisiting the whole thing also helps out. It's like with a spider's web, you do one layer, right, until you have the basic framework and then once you have the entire framework you revisit from level zero, you go back to the start again then – as a learner, okay?
>
> So, on the first go, you're the learner, you get towards a point. Now you reflect back onto the beginning but now you have hindsight, right, because you've been through it. Then once you go through that again – I suppose that's called revision - - -
>
> - - - but you can grasp it more now. Since you know the basics you can grasp more of the peripheral, it makes more sense now because you have context; you know how things work now. (Case 8, Interview 1)

It was this student (Case 8) who suggested that conceptual learning is like a spider's web. This is a good analogy at first glance as these webs are strong but can be broken in the right circumstances. Also, they can be built upon and repaired, and they link up various points of anchorage to create a network that can be traversed by the spider. However, spiders' webs are not collaboratively constructed (usually spiders are solitary web-builders), so the interactive elements of learning cannot be conveyed using this analogy. However, this analogy does assist in reviewing the concepts conveyed in the dynamic ZPD process (see Figure 6.2 above). It suggests that the learner's progression through conceptual thresholds concepts as zones of development should look more like a dynamically, continually re-shaped, three-dimensional web, with the learner building and meshing the concepts flexibly and intricately, rather than the staid, contained zones and measured step-wise image that Figure 6.2 portrays.

Rethinking threshold concepts as practice, Expert 1 (Interview 1) thought that the difficult nature of threshold concepts was because several, not everyday concepts need to come together to make sense of a practice in EBP. This harks back to earlier findings that demonstrated the troublesome nature of new knowledge. It confirms that even beyond the transformative threshold, there are troublesome times ahead for learners, in terms of Barnett's "critical action" (1997, pp. 67–68), the putting these concepts together and making them customary as ways of thinking and practising. In addition, development of learners' higher intellectual functioning is an essential part of conceptual development and threshold concept learning. In considering Vygotsky and the ZPD, it is possible to shift away from a focus on disciplinary mastery and instead focus on the learning of conceptual knowledge as a means to development of higher mental functions, including abstraction, reflection and other key critical thinking skills. With this approach, intellectual development becomes the overall outcome of higher education, with disciplinary knowledge as the mediating tool, echoing Barnett's (1997, p. 63) call for higher education to develop "critical beings" rather than merely knowledgeable graduates.

In trying to visualise the whole conceptual transformation process, there is no one single analogy that works to depict this complex systematisation. Instead, several diagrams must suffice as presented across this thesis. For the findings in this chapter, Figure 6.5 below summarises the major elements of the learner's movement from novice to expert with regard to the application of critical thinking, dialogue for learning and teaching and other key elements. The diagram shows the novice accumulating new concepts whilst integrating already systematised conceptual elements. This process is transformative, and results in news ways of thinking and practising. Critical thought, language as dialogue and inner speech are central to this process, with various external influences contributing and supporting the process. The new conceptual understandings build on each other as the learner crosses multiple transformative thresholds until they attain a competent level, and this continues onwards until they master the main elements of the discipline or profession and can be considered an expert. This diagram emphasises the essential role that critical thinking and language take in transformation in disciplinary and professional learning.

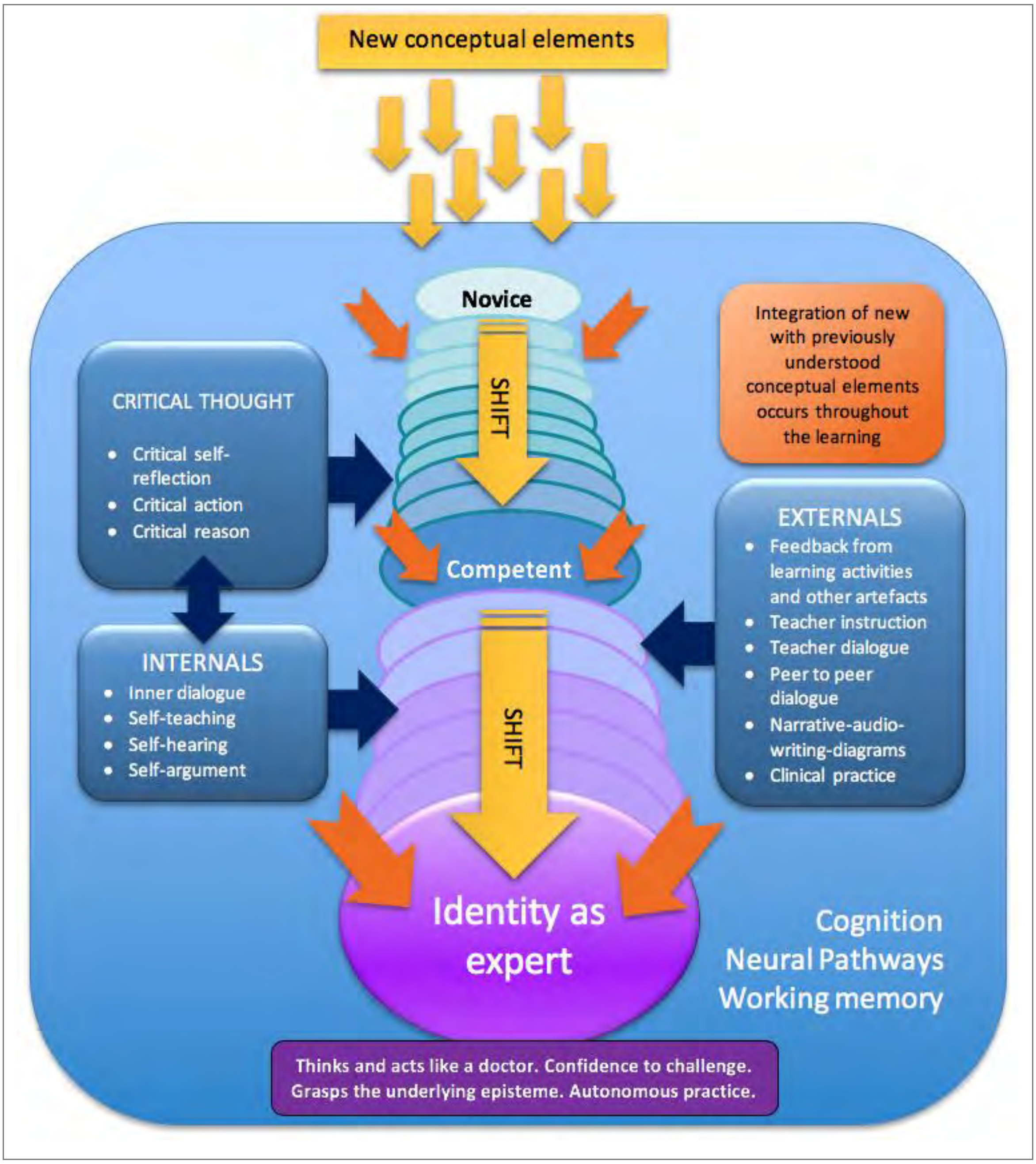

Figure 6.5 Main influences on transformational shifts from novice to expert identity

6.4.1 Critical Thinking Creates Transformation

Altogether the findings presented in this chapter suggest that critical thinking is possibly the key tool for transformation; it appears inherent within the learning process and almost essential in the ZPD/liminal space as the main initiator and assistance to the transformation process. However, it does not work alone; language as dialogue facilitates, assists and motivates the learning. One of the key outputs of the effort of thinking and learning is the learner's conceptual network or web of knowledge, and also their practice deriving from this and resulting in mastery and expertise.

Formation of conceptual disciplinary networks could be seen as the implicit objective of most of higher educational disciplinary curricula, but this is troublesome for students and academics alike. As previously discussed, networks of threshold disciplinary concepts can be seen as external, analogous versions of Vygotskian semantic networks outlined above. In their engagement with the discipline, it makes sense that each learner needs to create their own internalised "globe" network (Vygotsky, 2012, p. 211) or system of networked concepts that they can build upon in future learning. However, this bringing together of concepts in a functional web or network is problematic and, as shown already, it involves complex application of higher-level critical thinking skills. This is a highly individual journey that makes the development of teaching strategies even harder. Moreover, even though the resulting system of concepts created by each individual reflects their own learning journey, the introduction of simplified or generalised versions of disciplinary networks may assist the novice student in their learning. By identifying the basic systems or networks underlying these concepts, teachers should be better placed to provide students with conceptual maps of the best way to go forwards. Student cases said that it would be helpful to have a map that indicates which concept should be learned before another and demonstrates how these concepts fit together. This is similar to scaffolding of curricula. I recommend that it should be specific to each threshold concept and targetted carefully to their troublesome nature, at the same time offering a variety of learning strategies and options to allow for learner variability.

6.4.2 The Learning Journey Revised

At this point, insights from the findings presented above can be summed up as a revised conceptual learning journey for transformation; beginning before the ZPD/liminal space and extending now well beyond that liminal or upper ZPD threshold.

Pre-liminal Space, the ZFD

As the learner approaches the troublesome threshold concept, the learning horizon can appear very far away. Hence, it is important for learners to be critically reflective of their own current knowledge and understanding, and to be able to access this knowledge to assist their conceptual progress and development. It is clear from the literature and from this thesis, that awareness of tacit knowledge, spontaneous concepts and other academic concepts is vital for new concept learning and broader disciplinary understanding, whether this is a threshold concept or not. Hence, skills of self-efficacy, critical reflection and evaluation are essential at this preliminary stage. In addition, psychological resilience to weather change and uncertainty are helpful, as crossing the pre-liminal border is often uncomfortable and unpleasant.

Within the Liminal Space and ZPD

The learning process in this developmental space is most crucial to the learning journey. Conceptual development and resultant transformation influence the journey afterwards on to the overarching thresholds, the ways of thinking and practising and the disciplinary perspectives. There are essential skills that students identified in their learning of the transformative concepts and strategies that can enable this journey. Firstly, simplification as a learning strategy to make the troublesome concept easier to digest conceptually. Here, categorisation and breaking down of concepts are key critical thinking skills. Also, evaluation and assessment were mentioned as essential to the understanding of the concept. Following this initial unpicking process the concept has to be built back up in the learner's own fashion (but as close to the original as possible for the meaning to be intact). Students use abstraction as a tool to handle and view the elements, then bring in synthesis and integration skills for re-construction, layering and making meaning of the simplified concepts or concept components.

Post-liminal Spaces, ZAD

This is the application, problem-solving phase identified as a consolidation phase, and involves several critical thinking skills. Applying the threshold perspective and knowledge to a non-simple problem (e.g. a complex exercise or a case scenario situation) appears to concrete the learner's understanding so that they can reach that feeling of 'getting it' and they can then finally feel that they comprehend it. At this stage, they also feel more capable (though, not completely confident) that they can explain it to their peers or a teacher. Fresh application of this new way of thinking develops the way of practising – the threshold concept is applied alongside other conceptual elements and develops with further experience into the expert practice and mastery.

Barriers and Strategies

During the analysis, factors were identified that can prevent or hinder the ZPD becoming the ZAD or the learner from crossing of the liminal space and threshold. Some critical thinking skills appeared to affect these barriers and facilitating factors to learning. As described above, resistance to change is an important barrier. Partly, this is due to the struggle to give up previous understanding and everyday concepts, which are deeply rooted and known well. Lack of time or teaching support can hinder the learning here and the lack of support can initiate a switch to surface or rote-learning. The emotional cost of the effort to understand should not be underestimated. A stressed student, close to exam time, or feeling overwhelmed, frustrated or confused can find themselves unable to get past this strong emotion and can become disengaged and thus resort to avoidance or using rote-learning instead of deeper-learning strategies. On the other hand, many triggers were detected that initiated deeper application of thought, critical thinking and effort that led to ultimate transformation. Language as dialogue with others or for self, was especially influential. Certain teaching and learning approaches and also learning activities appeared to help the students in identifying that they should think harder and apply appropriate critical thinking skills and/or learning approaches. These approaches tended to be those that challenged the students the greatest but, at the same time, provided constructive feedback and support. Several students mentioned that being in the 'right frame of mind' was important. The calm and focused states promoted deeper learning and being 'clear-headed' was universally acknowledged as helpful for learning. In addition, feeling comfortable, safe, and 'ready' was also important for the students. The biostatistics and clinical teachers emphasised the importance of a safe and less confronting learning environment but stressed that challenge was essential for transformative learning.

Mapping this Journey

Mapping of the journey for or by the learner was an effective strategy mentioned by all participants. Vygotsky described an interrelatedness between academic and spontaneous concepts, so mapping each conceptual learning journey will most likely involve the identification of more elements of this dynamic conceptual process. These elements might include complex (and possibly threshold) concepts that define whole disciplinary topics. These over-arching, integrating transforming concepts delineate the larger conceptual disciplinary theories. These might be relatively abstract threshold or non-threshold concepts that are hard to elucidate but are essential concepts within the conceptual schema, e.g. probability. They might be key and/or threshold concepts that are actively acknowledged only when applied to a problem or learning situation (e.g. a clinical problem), for example, information skills and critical thinking skills. In addition, these elements might be 'ways of thinking' thresholds, rather than pure knowledge concepts. For example, it is accepted that tacit concepts, also called the "hidden curriculum" (Tsang, 2011, p. 3), are essential not only for conceptual learning but for applying knowledge and acting within professional practice.

Similarly, behaviours or approaches to the disciplinary ways of thinking provide the developing novice with a way forward to new horizons in acting the role of an academic or a practitioner (Davies, 2006; Perkins, 2008; Ross, Taylor, Hughes, Whitaker, et al., 2010). These are varied and complex conceptual elements with multiple connections. Certainly, providing learners with internal conceptual maps would be useful for many disciplines and professions. Kinchin and colleagues (2014a; 2010) have developed this literally, by advocating the development and provision of concept maps for students to follow through their learning in order to expose and make available the hidden curriculum and to identify and support their learning and integration of a subject's threshold concepts. By using concept mapping techniques, they aim to enable "dynamic transformation of knowledge structures, relating competence and comprehension" in the thinking of their students and suggest that this approach may help to develop these same "thinking skills" (Kinchin et al., 2010, p. 84). Indeed, they argue for introducing conceptual mapping visualisation across the undergraduate dental curriculum (Kinchin et al., 2011). This teaching approach could perform well as a curricular or learning activity strategy that aids students in realising both the direction and depth required for learning.

Triggers for Learning

This analysis identified key points where critical thinking is applied to conceptual learning of individual concepts and systematisation. Firstly, the triggers for deeper learning that identify the struggle points were important to students. Students need this identification of the problem that challenges them to initiate their critical thinking skills in a deeper way, otherwise it is easier to use a superficial learning approach and rote learn what they need to know, to pass examinations and not for the longer-term. Students spoke of rote learning definitions rather than getting to grips with the real concepts underlying them. One example is knowing that if the ‘p value’ is less than 0.05, then this means that a result is statistically significant. However, if challenged on this definition, the surface-learner will not be able to explain why this is so. Additionally, students often prefer to avoid deeper thinking as it is less comfortable and takes more effort. Most students admitted that they are well aware of what they do and don’t know, but often ignore this feeling and move on. However, they felt that if they don’t realise that they don’t know, then this is more of a problem. Being challenged (by a quiz or scenario, and exam or a problem) and feeling the ‘struggle’ can tell them that it they need to look at the concept more carefully; it forces them to rethink their learning approach. What these findings indicate is that critical thinking provoked by these trigger learning activities (e.g. clarify, make sense of, and apply), work as they trigger further, developmental critical thinking (e.g. abstractive thinking) that moves the student forward in the ZPD towards the higher learning threshold, and hence closer to the transformative threshold. It is good for teachers to challenge students often, but at the same time they should provide strategic advice to students about which critical thinking skills are most useful, and how to employ different ways of looking, relooking, employing and applying these concepts until they ‘get it.’

Language: Narratives, Analogy, Stories

Verbal narratives are vital for introducing and encouraging critical thinking eases the learning process. There is clear evidence that we learn stories more easily than unlinked, random ideas. This suggests that a narrative learning approach could be targetted to assist students in transformative learning. However, as with the mapping technique, not all students find this approach useful if it doesn’t suit their way of thinking. However, most students found analogy helpful, even if stories and scenarios are not. In Chapter Five, I showed that students often explained their understanding of a concept by drawing on an analogy. It seems that analogy can be used as critical thinking tool to identify the tacit and previously understood knowledge and ways of thinking, that can assist the student in understanding something new. This could be viewed as a form of layering or scaffolding of knowledge, drawing on the ZAD and pre-liminal understandings to take the learner through the ZPD, across the liminal space to full understanding of a different or a higher-level concept. Once again, this process can follow Howe’s abstraction-concretion cycle and the TCF reiterative journey across the liminal space (Howe, 1996). What appears to be happening is that the analogy creates a connection between the spontaneous and non-spontaneous concepts, the old knowledge and the new; bridging the knowledge and ontological gaps between the ZAD and the ZPD.

Mapping the conceptual territory involves being able to deconstruct and then to link the new concepts together to create comprehension. This involves basic skills, like categorisation, that are not complex, so are less stressful and easier for the novice student. This mapping of concepts appears to be a natural, critical process. The literature provides evidence that mapping of concepts is based on early developmental learning and that the culturally pervasive habit of storytelling facilitates a mapping conceptual process as a child matures. Stories and songlines are an ancient and naturally easy way of learning and teaching essential cultural information in communities across the world. Indeed, stories go a long way back in human history and development. Australian Aboriginal songlines are a rich example of the conceptual mapping of geographical links with the environment, melding children with their country (Kerwin, 2011). These sung stories provide a culturally rich and effective way of passing down essential community knowledge as "oral maps" of the landscape from one generation to the next and sharing with neighbouring peoples (Norris & Harney, 2014, p. 11). Songlines as maps are conceptually structured to provide navigation within the land to find food sources and to remember ways across territory, using the stars to do so, as they are "often mirrored by songlines in the sky" (Norris & Harney, 2014, p. 11). The Dreamtime songlines are more than this, as they are the cultural heritage and consciousness; Dreamtime is not history, it is considered to be the past, present and future (Bell, 2002). As Kerwin (2011, p. 259) eloquently states, "Australia's topography creates a context for Aboriginal ways of knowing and being." Who you are, is where you are; this is spatialised memory, with a practical and cultural purpose. Cultural necessity ensures the memory of important places and purposes using a mythology to frame the knowledge transfer and is not unique to Australia. We use these techniques in everyday life without appreciating them. We are culturally initiated into learning from a young age through stories and maps. Thus, a map can provide knowledge as visual narrative, and a story can provide a visual map for learning.

CRITICAL THINKING AS A THRESHOLD CAPABILITY

This chapter has shown that the learner's critical thinking skills are a fundamental part of the conceptual development process. These skills act as enablers, forcing and cajoling active and deeper thinking; they trigger the application of richer, more analytical and abstract thought. The key critical thinking skills acting within the ZPD/liminal space were: categorisation, simplification/breaking down of elements, analysis and evaluation, abstraction, comprehension, interpretation and explanation for making sense of a topic, and synthesis and integration for bringing all the meanings and concepts together. In addition, the mapping and creating of one's own conceptual pathways should be considered a critical thinking skill, as should the inner speech ways of thinking of self-interrogation, self-questioning and self-motivation. Throughout the examination of the conceptual learning data (of audio, transcribed and reflective journal formats), critical thinking was very visible and seen as vital in aiding and abetting language as the great-communicator of the mind. Together, language and critical thinking construct transformative conceptual development, via dialogue, inner speech, visual thought and mental imaging.

So, critical thinking skills are necessary for the learner to travel the full length of her learning journey from novice to expert via many successive or simultaneous iterations of crossing from pre-liminal mode to post-liminal mode, or viewing the ZFD from within the ZAD and thus being enticed to enter the ZPD and transforming and stepping into a new ZAD. Critical thinking explains, integrates, and concretises understandings. If inner speech is the necklace that threads all through the mind linking up the mind's audio, speech, conceptual and memory areas, then critical thinking is the thread that binds the whole of conceptual thinking together and transforms separate pieces of information and fleeting understanding into new and exciting ways of thinking and doing. The model below (Figure 6.6) attempts to summarise and visualise the whole conceptual learning process with reference to the zones of development and the modes of the liminal process. On finishing this research, viewing critical thinking from the Vygotskian–TCF perspective and with the findings in mind, I find that there is a good argument for critical thinking as a *threshold capability*. Critical thinking acts as a bridge across gaps in understanding. It brings together the concepts, and ideas, making meaning of them and forming understandings between them. If considered as either skills or conceptually, it is itself troublesome in knowledge and language, irreversible once understood, and integrative of other complicated ideas and concepts. It has its own discourse and is reconstitutive; one is capable of *being* critical, if one's ontological view of the world has changed. Thus, critical thinking is the main threshold capability that fashions academic concepts from everyday learning, scientific ideas and conceptual arguments. It can create threshold concepts and fundamental ideas within one's mind's eye. Critical thinking joins concepts and ideas together in a web-like system in our mind to explain and display concepts and provide meaningful links between them, readying them for deployment in practice, within our work and for our ways of being. Critical thinking is the great integrator.

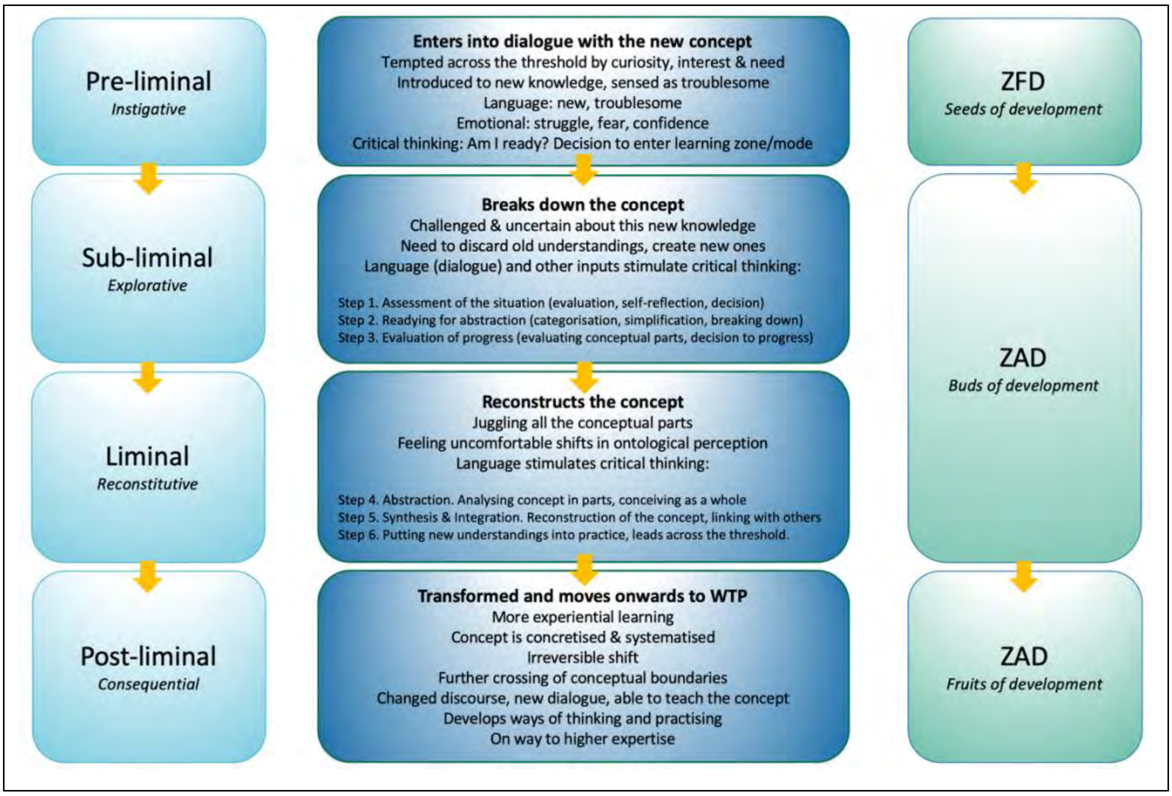

Figure 6.6 Summary model of transformational conceptual learning

The TCF liminal modes and character are represented on the left-hand side, and the Vygotskian zones of development on the right. ZFD: zone of far development; ZPD: zone of proximal development; ZAD: zone of actual development

CHAPTER 7:
CRITICAL THINKING FOR TRANSFORMATIONAL LEARNING

"Consciousness is reflected in a word as the sun in a drop of water. A word relates to consciousness as a living cell relates to the whole organism, as an atom relates to the universe. A word is a microcosm of human consciousness."

(Vygotsky, 2012, p. 271)

This exploration into the critical thinking employed by undergraduate medical students in tackling troublesome, transformative concepts within the medicine curriculum has made surprising and valuable conclusions. It has confirmed previously identified threshold concepts and other conceptual elements in evidence-based practice (EBP) and medical biostatistics, and it has detected new ones. Further, it has begun to unpick how these elements interact as conceptual networks during new learning and has unveiled how these elements help students develop clinical expertise. This Vygotskian perspective of the threshold concept framework worked with the abductive analysis surprisingly well, and has been shown to be an innovative, valid and practical way of examining conceptual learning. This concluding chapter draws together the most significant and interesting findings of my thesis. Firstly, the main findings from the three analysis-discussion chapters are highlighted. In the second section, study limitations are discussed, and in the final section, the major recommendations and implications for undergraduate healthcare and higher education disciplines are presented and discussed.

7.1 LANGUAGE AND CRITICAL THINKING AS BRIDGES

This thesis examined the crucial tipping point of the troublesome conceptual learning process highlighting the social-semiotic ZPD/liminal space where higher forms of meaning-making are facilitated through learning artefacts, and through tools such as signification, dialogue and critical thinking. Since my research began, Land et al. (2014) have made progress in this area by developing a sign system schematic to illustrate the conceptual processes involved in threshold concept learning. This offers a useful heuristic tool for supporting learners through the threshold concept liminal space and could build upon disciplinary work where semiotics has been used to clarify thinking processes for conceptual learning in statistics and mathematics (e.g. Bakker, 2004). However, I found that there was more to learn beyond semiotics. Significantly, language is used in teaching and learning as dialogue, narrative and analogy to directly and indirectly initiate and maintain the crucial role of critical thinking in conceptual learning for transformative learning. My findings emphasise that inner and external private speech is used both actively and subconsciously for self-teaching as self-thinking, dialogic learning, and self-challenging discussions for conceptual learning. I conclude that both inner and external speech are essential for studying and conceptualising for transformative learning. This is important, as teachers could easily disregard the inner dialogue that goes on when students are quiet, silent, or studying elsewhere. In recognising that language acts as a primary bridge-communicator for the learning experiences via signification by language-thinking, I have re-emphasised that semiotic language facilitates inner speech, which in turn initiates critical thinking for transformative learning in the liminal space. Specific cognitive processes are in place to facilitate these processes in the brain, and cognitive psychological research is discovering more about this every day. The importance of narrative, analogy and metaphor in aiding this process was another key finding.

Overall, language is central to conceptualisation and meaning making of the threshold concept and other conceptual learning processes for these students. I recognise that it is not unique in being useful in assisting students to overcome the troublesome nature of these thresholds. However, I believe that language is universally involved in this process. My data shows that language connects the visual mediation signs (e.g. diagrams, concept maps, pictures) to conceptual learning, which was an unexpected but corroborated finding. Additionally, language stimulates and uses the affective nature of learning purposefully and automatically; language influences and is influenced by emotional mediators acting as a motivational as well as an inhibiting sign. Furthermore, aside from stimulating and maintaining the working memory loops in the brain, it appears that language stimulates the critical thinking necessary for that deeper contact with the troublesome edge of threshold concepts. It appears that language-thought-knowledge acts as a continuum; language is the linking bridge that simulates relevant, appropriate critical thinking as a further conduit for conceptual learning for ontological and epistemological transformation. On reflection, this abductive analysis has shone a Vygotskian lens into the ZPD/liminal space and uncovered the central roles that language and critical thinking play in the integration of concepts for transformation.

7.1.1 Intricacy of Language and Critical Thinking for Learning

Harking back to Vygotsky, he famously said "a word is a microcosm of human consciousness" (2012, p. 271). This was strikingly apparent in my data as words as dialogue were crucial in transformative conceptual learning. From this it is easy to extrapolate the importance of instruction through language, discourse and discussion. Within the data, I found that language was active both in inner speech and self-instruction and within the external speech of instructive interaction with teachers, peers and online resources. On the other hand, the critical thinking discovered here was more complex. It was difficult to unpick the processes involved in this thinking, as they cannot be directly observed. However, I have shown that critical thinking is encouraged and initiated through dialogue as instruction by teacher, peer and self. Meeting troublesome knowledge and language in the pre-liminal space acts as a trigger for deeper learning. Therefore, identifying these pre-liminal moments and fostering helpful critical thinking skills here with teaching strategies and learning activities could improve the transition into the ZPD/liminal space. Furthermore, critical thinking is essential for learning threshold concepts and networks for fulfillment of the ZPD and the full threshold concept liminal journey. Within this zone-space the complexity of the interactions of dialogue and critical thinking become apparent.

At the same time, analysis showed that this struggle was necessary for the engagement of the higher thinking processes, such as abstraction and problem-solving. The challenge needs to be there for deeper thinking to be initiated and for the student to be fully engaged. I detected a new intricacy in the types of critical thinking required to break down and build back up the concept and create conceptual networks. Definite stepped processes were apparent for how students handled these troublesome concepts. These steps involved an explorative, then a reconstitutive process. Initially, it is imperative to make the concept easier to digest mentally, only then it is possible to reconstruct it and fit it into their personal mental conceptual schema. So, the first step is evaluative to assess the situation, followed by a process of breaking down the concept, mostly by simplification and categorisation, and then evaluation of the progress made. This is followed by abstraction that allows the student to analyse and evaluate what they have discovered in dissecting the concept. At this point, students are able to see the concept (in its component constituents) as abstraction aids by creating a visual or mental framework for the reconstruction. Then comes synthesis and integrative approaches to bring the concept back together in one piece. At this point there can be a welcome transformative 'Aha!' moment, when the conceptual knowledge has suddenly connected internally with the learner's previous conceptual understandings to create a new conceptual map or network.

Furthermore, the final step is a shift to a new ontological, disciplinary perspective that arises after the application of this new conceptual knowledge in practice. This involves the learner actively applying the new conceptual knowledge, for example in problem-solving exercises, in more authentic activities such as appraising a journal article or taking a history and examining a patient using the principles learned. This in-practice application seems to ensure that the concept interacts with and transforms with other key conceptual elements and skills for a further ontological shift of perspective. Only then can this new way of practice develop into an understood, fully irreversible and automated way of thinking and practising, echoing Kolb's (2015) experiential learning cycle. On putting the concept into practice, the student transforms beyond the original ZPD/liminal space, into a new ZAD and post-liminal space of practice-learning. With each transformative shift, the student becomes more competent in the practice as she gets closer to the disciplinary expert way of thinking and practising.

Throughout this learning process, I detected interesting differences in student learning approaches. Some students thought and studied more visually, some preferred textual and speech, others preferred listening, and most students used a combination of these approaches at some time or other. However, the universal strategy appeared to be self-teaching by self-testing, self-questioning and self-encouragement, through conscious and sub-conscious inner speech. This inner-teaching combined with external dialogue from instruction with peers, teachers and interactive online resources to stimulate critical thinking processes, and to choose appropriate learning approaches and learning state. Admittedly, this might be only one way of dealing with threshold concepts, but all the participants talked of these strategies and approaches as important for their learning.

The apparent remodeling of the individual's conceptual schemas is Vygotskian in its perspective, relying on the developmental aspects of conceptual learning. Spontaneous concepts and scientific concepts merge, to be reformed, and spontaneous concepts are lifted up and made more concrete, so the learner loses the older, often child-like understandings to gain more academic perspectives of key concepts. This developmental perspective has illuminated this process to enable further research for educational and developmental purposes. Additionally, it shows how important it is for teachers to remember the importance of tacit and previous knowledge. Moreover, conceptual learning is a process of deconstruction, reorganisation, reintegration, reformation that takes mental and emotional energy. Hence, I recommend that both direct and indirect instructional provision should be employed in supporting the process.

In summary, language is a bridge to critical thinking for understanding for difficult learning, but critical thinking is more than a bridge; it is a generator of transformation. Critical thinking initiates explanation and meaning and actively leads to the irreversible epistemological and ontological shifts of threshold learning via Vygotskian systematisation and concretisation of conceptual networks.

7.1.2 Theoretical Implications

The Vygotskian perspective works well with the TCF, and the abductive analysis approach, despite its novelty, was relatively easy to use. It seemed natural to approach these data in this way, and to employ theory dynamically in this exploration. The three initial touching points identified between Vygotsky's theories and the TCF developed into strong and useful theoretical intersections, which provided an excellent framework for the analysis and worked well with other related and similar models. There was a powerful synergy between the relevant Vygotskian theories and the TCF that assisted identifying the threshold concepts in EBP and medical biostatistics. Also, this process revealed the important role of language and inner speech and went on to clarify how critical thinking aids transformation. This framework could be used in similar way for analysis of threshold concepts and conceptual learning in another setting, or as a methodology within a multi-method Integrated Threshold Concept Knowledge approach (J. Timmermans, & Meyer, 2017).

7.1.3 Major Implications for Teaching and Learning

My findings confirm the importance of dialogue in learning, specifically in stimulating critical thinking for creating transformation conceptual learning. For their learning to be successful, students should be receptive to instruction by both external dialogue and self-teaching, and also, they should develop appropriate abilities in critical thinking, and be able to deploy them quickly and effectively. Here, Barnett's critical being model (1997, pp. 103–105) and the triadic dispositions (Perkins et al., 1993) are useful once more in recommending how to develop these essential critical skills further. The current emphasis on disciplinary approaches and research in education has abandoned the original ideas of diversification of school and disciplinary learning with wide perspectives. So, it is necessary to reemphasise the teaching of abilities for learning ways of thinking and practising. To create an adaptable workforce ready for the changing face of employment in this technological age, public and privately funded think tanks are recommending a focus on generic, basic skill-learning, broader capabilities and creating opportunities for students to learn across disciplinary boundaries from school (McCrindle Research, 2018) to higher education (Innovation and Science Australia, 2017). This contrasts with new graduates (Bolton et al., 2019) and employers (Commonwealth of Australia, 2019) who appear satisfied with the current status quo and current excellent employment prospects for skilled graduates.

In medicine, there is a growing realisation that the momentum of technological advances, including genomics, machine-assisted practice and 'big data' will change the future of practice of medicine and the role of all healthcare workers, including doctors (Hodson, 2018). Universities are beginning to realise that curricula need to change to prepare students for this new workplace and rapidly changing roles (Innovation and Science Australia, 2017). Indeed, inter-professional learning is being recommended as a way of developing curricula and to plan for these inevitable role and workplace changes (Dunston R et al., 2016). My research echoes this call for change, but emphasises the need for graduates who think critically, creatively and reflectively; I believe this is the key to survival in the future workplace. By focusing on disciplinary knowledge at a time when computer-accessed knowledge is on the rise, we may be disabling our students for their future. Thus, my original query as to whether graduates should be critical thinkers with the ability to put thinking into practice across a range of disciplinary knowledge areas, has added emphasis and impetus for the future of medical education. In addition, it seems certain that creativity and reflective practice will also play a key role; 'adaptive' learners may be the answer to the future.

For a better future, conceptual learning needs to be challenging, but well supported. We should aim to support students to become Barnett's critical practitioners, as well as disciplinary experts. Graduates need the skills to transfer their critical practice across disciplines, to be able to adapt and survive within a rapidly changing workplace environment (Baillie et al., 2013; Barnett, 2004). Hence, the focus in medical education should be the graduate as an adaptable, critical practitioner.

7.2 EVALUATION OF THE STUDY

My learning journey in this research has spanned eight years, which seems a long time, but it is only two years longer than a medical student's full undergraduate program. The first-year students whom I was teaching in 2011 when I began this research, will be just starting their first-year post-internship and heading into further training. Meanwhile, my learning journey has been very different. I have witnessed great interest and successful research following Meyer and Land's (2003) original threshold concepts idea. I have learned valuable insights into the Vygotskian perspective, especially around language and thought and this was crucial in adding a deeper theoretical approach to my research.

7.2.1 Main Issues Arising

In terms of research scope, this thesis concentrated on examining the conceptual learning experiences of undergraduate medical students with different levels of expertise in the curriculum, focussing on their learning of EBP and biostatistics at UNSW. The main aim was to examine critical thinking used by students at conceptual transformation points. This main research aim was achieved. The evaluation presented in Chapter Three shows that the general methodological approach of this thesis was sound, and the few areas of concern were of minor impact considering the methodology and the study direction and aims. The research is well and truly anchored in the relevant threshold concept literature, and this combined well with the Vygotskian conceptual-developmental perspective. The credibility of the research is strong despite the reliance on post-incident reflective recordings. The findings are trustworthy and authentic, and provide useful, original outcomes from a valid analysis process. The reflexivity of this research process was vital to maintaining the research momentum across eight years and providing a self-evaluative framework as a sole researcher. I heeded sensible advice to keep systematic, reflective memos regarding research decisions, feedback from supervisors, conceptual struggles and conceptual transformations. These provided further data for the study and created a vital connection across these many years of part-time research. Furthermore, I have demonstrated the impact and transferability of these findings in terms of the important implications for education discussed above, and in the recommendations below.

The main analysis method functioned well. The abductive analysis was a new methodological approach, but I found that the process worked well. It seemed to generate its own 'level of steam' that kept the cycle of theory, data, interpretation, to back to theory again, powering onwards. My research is very unlikely to be completely replicable, but I have provided adequate information in case someone wishes to perform a similar study. My relationship to the research is clearly shown throughout this thesis – it is close and interwoven at times; I became a part of it, but at the same time I am able to step away from it (defamiliarise) and re-view it from different angles, apply alternative casing techniques and handle it dispassionately. Overall, I consider this research to be adequately dependable in process and confirmable in the sense that others have already, and in the future should be able to find similar results and derive comparable theoretical findings.

In terms of transferability, I believe that these findings, although derived from a small sample of participants at a university in Sydney, Australia, should be applicable to medical and other health care education in the teaching of evidence-based practice both undergraduate and postgraduate levels. Educators of evidence-based practice in healthcare and other professional practices and teachers of statistical curricula should find the identification of the conceptual elements in EBP and medical biostatistics useful for designing curricula and learning activities. The insights into the student learning should be of interest and useful to educators who are struggling to understand how their students are crossing the liminal space. Lastly, evaluation of the authenticity of my research showed that the internal validity and conduct of the research was good. I have applied my recommendations to my own teaching practice, introducing team-based learning focusing on key EBP thresholds for developing ways of thinking and practising in the third year of the medical program. Dissemination of my findings is planned, so this research could have a wider impact and initiate improvement in student learning outcomes elsewhere.

7.2.2 Anticipation of Criticisms

Firstly, I acknowledge that there was a lack of detail within the data on critical thinking. This was due to students and experts finding it hard to engage with my request to talk on this topic. This is unsurprising as the thinking process is internal and partly subconscious or automatic, so it is difficult to access except by individual reflection on thoughts. Also, when trying to learn, one rarely examines how one is learning at the same time. I asked the students to reflect as soon as possible after a troublesome or conceptual thinking, but they admitted that, even if they did reflect during the process, they often didn't write it down until later. Considering these factors, I am pleased with the gems of information uncovered from the data, and greatly appreciate the participants' efforts in producing the journal reflections for my study.

Secondly, as touched on above, the issue of my role as sole interviewer, analyst and writer of this thesis could be an issue if this was a different type of research. However, with the care, controls and caveats put in place (especially in the analysis and interpretation stages), I used this design issue to be a positive part of the study. The abductive method worked well, allowing the inclusion of other theories, results and interpretations from the relevant literature to assist and add alternative casing opportunities for the analysis. My supervisors and colleagues acted as sounding boards, providing an extra layer of theoretical analysis that was then fed back into the next step of abduction. They pointed out possible alternative scenarios and were careful to add their advice when they thought that other interpretations could be made, or different perspectives might be useful. I believe that the analysis has not been deliberately led astray or missed anything major. Another way of analysing this could be from the social constructivist approach, the research paradigm used for the thesis, which would conclude that I found what I found because it was me doing the research – my input and my approach made this research what it is. This was a personal research undertaking and the understanding is mine, derived from Vygotsky, the TCF and other relevant models. I maintain that this is reasonable and expected within the limits of this qualitative research approach and acceptable within the limits and design of doctoral study.

Thirdly, there were areas that I was unable to examine as closely as I would have liked. For example, the influence that the learning environment had on the student outcomes was not fully explored. Martindale's thesis of threshold concepts in research and EBP for nursing students found that there were "troublesome environments" (2015, p. 230) especially related to the EBP teaching and curriculum design. On reflection, my study missed an opportunity to ask students to record the external factors affecting their transformative or troublesome learning experience, and what impact that they felt this had. This might have yielded interesting data but could have also taken the student's focus away from my primary purpose: to examine the critical thinking element of the learning.

In analysing the data for specific comments regarding environment and teaching characteristics, I was able to identify interesting positive factors, including peer teaching and importance of dialogue in the learning, the positive impact of clinical environments on quality of learning, and the usefulness of artefacts such as online learning resources. Further study could reveal more about the influence of these factors.

A final important criticism that could be levelled at this research is that it reflects, even mirrors the current educational paradigm and that this limits its findings. I would agree with the first part of this criticism but think that this is almost necessarily so. I chose to work within the current sociocultural constructivist, student-centred approach to teaching and learning in higher education and my theoretical methodological approach narrows to this perspective. However, I suggest that the abductive analysis used in my research continually emphasised examination of the surprising elements arising from the data. This method forces the researcher to look to alternative options, to consider opposing views, to contemplate other possibilities. I was careful to be sensitive to the surprising elements of this research – aided by my curiosity for the intriguing, the unknown, the mysterious and the down-right confusing. Noticing and engaging with these odd moments in the analysis provided some of the richest findings and interpretations, for example students declaring that they trusted peers as teachers but at the same time not trusting them. Also, unexpected and fascinating was the discovery of the inner workings of conceptual thinking, especially around the students' character-infused inner voices, role-playing for self-teaching and active self-questioning for learning. I doubt that I have uncovered all the available information from these data, but I believe that I have found worthwhile ideas that are already helping my teaching and could generate further research and new theories to improve students' conceptual learning. At the same time, I have learned a great deal from my students, my colleagues, my discipline, and myself about the topic, about collaboration in research with participants and colleagues, and about qualitative research methods.

7.3 RECOMMENDATIONS

This thesis represents a significant, original contribution to the threshold concept theoretical research. It is an innovative exploration of the Vygotskian theories of conceptual learning with the TCF provides new ways of looking at the less well understood threshold concept liminal space. By aligning Vygotsky's conceptual zones of development with threshold concept liminality, further depth has been brought to the threshold concept theoretical framework. This advance offers an additional, more powerful lens for investigating the individual learner's journey across troublesome conceptual thresholds. Furthermore, the illumination of the conceptual process by identifying the steps of critical thinking alongside the insights into the importance of the learner's inner speech in this process, extends the way forward for pedagogical research in this area. Altogether, these new theoretical perspectives should enable the development of new tools and approaches for assisting students across the liminal threshold.

7.3.1 Future Teaching and Learning Directions

From my research experience, I believe that identifying individual and threshold concept networks for teaching in the current higher education climate and learning environment works well and wholeheartedly recommend this to other educators. Furthermore, considering the ZPD/liminal space could bring teaching closer to the central processes of conceptual learning. We are only just beginning to understand the systematisation that occurs here with inner speech, critical thinking and peer and teacher support. The design of educational activities and curricula should target assistance to the student within the ZPD/liminal space with this in mind. For future research, a combined teaching and action research approach could observe the expert directly discussing with the learner and taking them through the ZPD/liminal space experience. It would be necessary to identify the conceptual elements of the topic for the individual learner, but this approach could test new support systems (such as conceptual mapping of the process) designed to help guide students through the process. I encourage teachers in secondary and higher education to use the Vygotskian–TCF approach for curricular development.

My main educational recommendation is aimed at supporting the development and use of each student's mental tools for greater efficiency of learning across the liminal space. It is vital to support language, especially inner speech and reflection on instruction. As critical thinking is crucial here, generic skill development and scaffolded learning activities could support student application of the critical thinking steps for transformation. The main strategies derived from my research are considered below. These would gain from collaborative projects and input from current scholarly teaching disciplinary recommendations, e.g. Garfield & Ben-Zvi (2007) from mainstream statistics.

Mapping and Guidance

Identifying and mapping the conceptual elements of each main element of the curriculum is essential and fits well with the current curricular approach of having clear student learning outcomes. Sharing this mapped journey with the students is necessary, but more effectively, teachers could assist students to map their own journey following a basic conceptual map developed by the experts. Providing structured videos and other online interactive tutorials designed to activate the pre-liminal triggers for entry into the liminal space could assist this difficult learning moment. Also, supporting the student's movement onwards in crossing the liminal space and onwards into the "chains of practice" (Kinchin et al., 2008, p. 316) is also necessary. It is obvious that students need more assistance with conceptual terminology and one way of helping this is by providing detailed glossaries with well-explained definitions. This is simple, accessible and has proven effectiveness in medicine (Hsu, 2013). Introducing a new individualised approach to scaffolding could target the learning at the individual's own learning journey across the developmental zones/liminal modes. This could be supported by including carefully designed formative, dynamic formative learning activities and assessments within the curriculum at key points where the students most need to check their understanding and have feedback on how to continue their learning. Detailed, targeted, individual feedback is recommended.

Assistance with Cognitive Processes

Modeling is recommended for imitation of the key difficult steps in learning, by providing worked examples of the process of simplification and meanings, with similar practice questions. This should include assisted learning and guidance to participants regarding the critical thinking steps to assist in those troublesome moments, when they struggle in their learning. Also, encouragement of cognitive self-instruction could strengthen this powerful learning tool. This could be achieved by explaining to students that self-talk and self-teaching techniques are useful and encouraging their use through formative learning activities for self- or in-class study. Another approach is the structuring of learning activities to encourage and enhance peer-learning for the troublesome concepts within class. Also encouraging students to study together outside of class whilst providing expert guidance, could utilise both peer and instructor dialogue. To promote the active discussion of concepts that are threshold concepts or threshold ways of thinking and practising, teachers could provide opportunities for this within all learning activities. Finally, as a general assistant to the above strategies, providing effective, constructive, timely feedback to students is an important stimulus in furthering conceptual learning.

A general recommendation (that I have already implemented) is the partnering of experts with students to explore the curricula and for joint creation of the learning environment, learning objectives and learning activities. This appears to increase engagement and improve learning outcomes (Cook-Sather & Luz, 2015). Considering the conceptual challenges involved in my discipline, and the surprising maturity and depth of reflection that I encountered in my small sample of students, I hope that this partnership will lead to improved learning resources with improvement in student engagement.

7.3.2 Future Research Directions

The Vygotskian-TCF framework intersections, coupled with abductive analysis, should be considered as a new methodology for other educational research questions. In terms of research methods for examining inner speech and self-teaching, I recommend considering audio recording sampling as used in the current inner speech/inner voices research as Descriptive Experience Sampling (DES) (Hurlburt, Alderson-Day, Kühn, & Fernyhough, 2016, p. 3). Despite its novel approach, this method has gained considerable purchase within this research area. DES could provide an alternative insight into the student learning experience by forcing reflection and comment at random moments when students are studying. Alternatively, richer data might be obtained from direct recording of students as they talk aloud, narrating their navigation of a threshold or troublesome conceptual learning points. This could be facilitated by expert teachers, acting as sounding board and guide for the ZPD/liminal space.

The importance of peer interaction was an unanticipated finding and it would be worthwhile to take a closer look at this with regard to threshold concept learning. Peer teaching and learning and online instruction are being increasingly introduced into curricula. Also, there are instructional peer interactions that teachers rarely see or notice as they are outside of class, but my research showed that these modes of learning assist greatly in the dynamic conceptual and transformation learning zones. Certainly, it would be worthwhile examining these instructional interactions in terms of the critical thinking skills that they engender for conceptual learning and compare these to teacher-student interactions. Depending on the findings, it might be useful to examine how the curriculum can support these activities better.

Another potential area for further research is conceptual mapping. This method of recording reflection was not taken up by many of my participant students (one student used it although he was not happy with the result). However, my research findings suggest that students are thinking in this way and are desperate to have expert assistance in mapping the liminal journey. Conceptual mapping could be a valuable tool for examining conceptual learning and consequent curricular design. Taking a leaf out of previous successful research using this method (e.g. Kinchin et al., 2010; Kinchin & Miller, 2012), this approach could be used for examining the conceptual simplification and rebuilding steps that enable the transformative journey to conceptual integration. To assist my students, I've created a tentative re-mapping of the threshold concepts of the evidence-based practice cycle, presented below in Figure 7.1. This model requires further thought and discussion but shows how the learning of the individual EBP threshold concepts (alongside other conceptual elements) integrates into a practice cycle (the inner circle). The outer circle represents practice-based learning, and shows how EBP as practice develops through experiential, professional learning, initiating clinical and professional ways of thinking and practising. Through this cycle of learning and practice, the student goes on to develop her evidence-based clinical expertise and clinical practitioner identity.

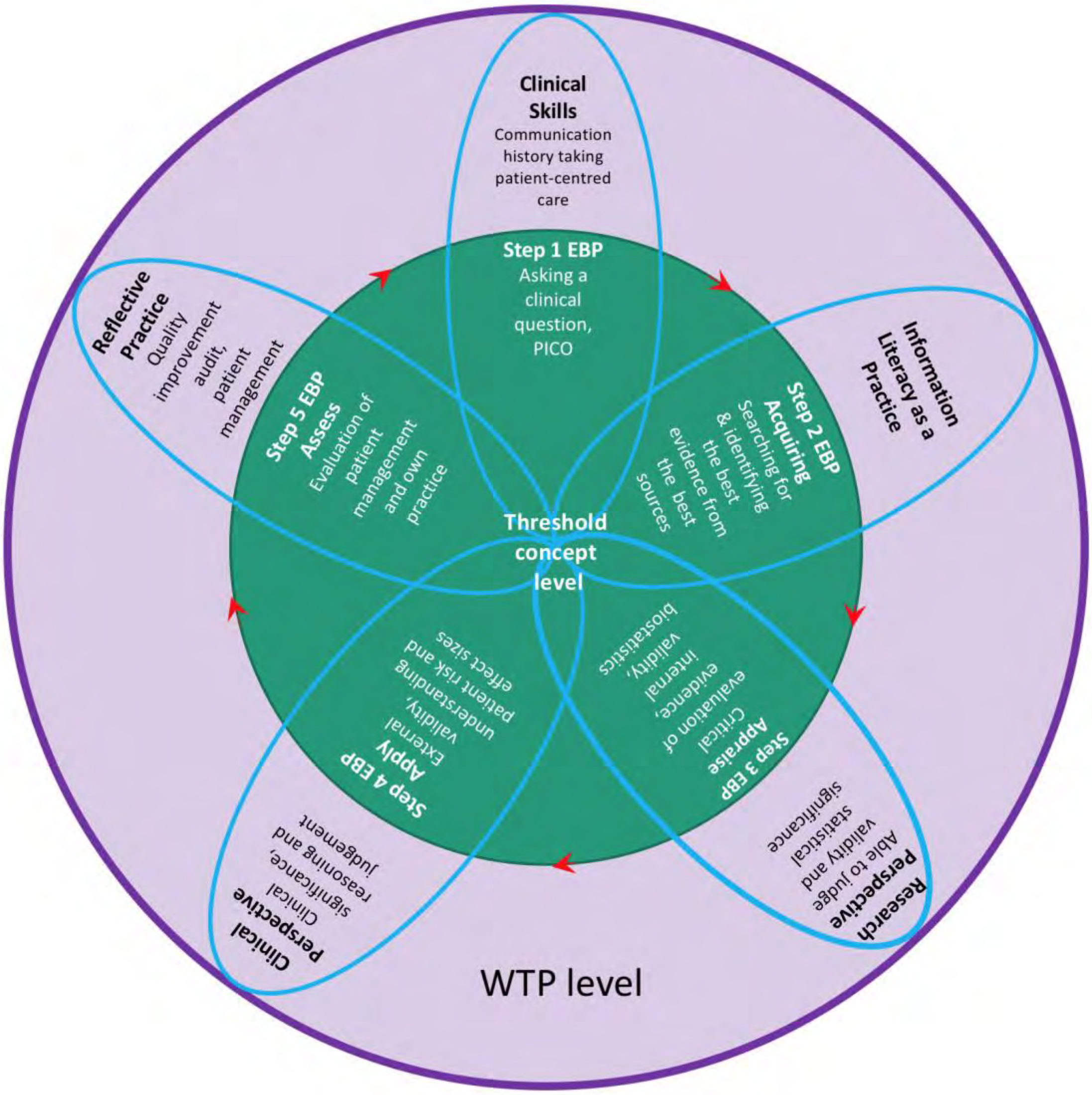

Figure 7.1 Re-mapping of the evidence-based practice (EBP) cycle to demonstrate the related ways of thinking and practising (WTP)

CRITICAL THINKING AS TRANSFORMATION

In this chapter, I have brought together the main findings of my research and demonstrated how these can assist in learning and teaching and future research. Much work remains to be done in clarifying, visualising and modeling what is happening in the learner's mind as they engage with threshold concepts and traverse the ZPD/liminal space. However, this thesis' examination of this crucial learning process has provided a new way of viewing this process using a Vygotskian-TCF lens. It has revealed that language acts as the great-communicator in the inner cognition that is essential for systematisation and making meaning of concepts. Subsequently, critical thinking is the key for unlocking the doorway to transformation. At a time in higher education when skills are becoming more important than knowledge, I believe that Barnett's idea of the critical practitioner is key to the future of university-level education. I am reminded once more of the advice that I give first-year students, that much of the medical knowledge they learn for their medical exams will be out of date by the time they enter the medical workforce. I reassure them that if they gain crucial learning skills, these should see them through their careers, providing them with the ability to continually learn and transform, and so to progress onwards to higher levels of expertise in clinical and research practice. Future innovations are going to change the way healthcare services work, bringing machine-assisted diagnosis and decision-making, and unpredictable changes to interprofessional practice. As with doctors across the ages, it is essential for future graduates to struggle with conceptual revelations to stimulate their metamorphosis to new perspectives so that they can put their skills, knowledge and evidence into practice as effective, safe clinicians. Language and critical thinking are absolutely fundamental to this transformation.

CODA: PERSONAL REFLECTION

Undertaking this doctoral study was a voyage of discovery, as a teacher and as a learner. This PhD has opened my eyes to a whole new way of thinking and to research and, as a result, I have additional, powerful lenses with which to view my students' learning. Coming from epidemiological and quantitative approaches, my experience of qualitative research was minimal, but I was fortunate to gain an early grounding in qualitative theory with my initial MPhil coursework. This choice of a qualitative, abductive research approach celebrated rather than repressed my role within the analysis and fostered self-reflection. Slowly at first, my research became a continual cycle of reflection on the data and research approach, my individual experiences and learning. I used both electronic and pen and paper memos and concept maps to record key observations related to the data collection. As I reflected on my research, my personal experiences and the key learning points that I encountered, these memos acted as a learning diary and as a research process journal. Reflective elements were processed alongside the participant data in NVIVO and thus contributed to the research findings.

Being immersed in Vygotsky at this stage of my teaching career, was a surprisingly exhilarating experience. Having started my MPhil research using Bourdieu's theories of habitus, agency and power, the switch to Vygotsky was risky, but worthwhile. His theories worked so well with the TCF that it felt as if they were made for each other. The resultant theoretical framework interwove easily with the data, acting as a recurrent sounding board. On contemplating this abductive process, I realise that it was both moving and daunting to acknowledge the 'multiple truths' and 'range of meanings' as they arose. At times I felt like a transmitter that picks up the threads of an interesting signal to broadcast it clearer and wider. If I concentrate, the participants' voices echo in my head even three years after the first interviews. My inner ear can hear their them; they are still passing on their meaning to me. This suggests that the constructivist environment created for this research encouraged the participants' contributions to be active rather than passive. Thus, their contribution was the central pillar of this research.

My main findings were that language and critical thinking act synergistically for clarification and to initiate and sustain transformation for conceptual learning. I fear from a distance that these findings appear to confirm what we already know. However, my investigation revealed the critical thinking steps that learners take when they are undergoing this transformation process, and the vital role of language in this process. With this new information, I aim to develop and test new teaching methods to assist my students in their learning journey to become critical practitioners. In addition, I am considering new avenues of research to discover more about the role of inner speech in learning; there is much more left to discover about these innermost conceptual learning practices.

My intention was to write the thesis completely in the first person, but unfortunately this didn't work out. Instead, I have turned to the first-person at key points so as to write my thoughts into the discourse and enhance the 'researcher voice'. I enjoyed all the stages of this research; however, I am no different from those who came before me in finding that 'getting my thoughts down on paper' was the most difficult step. Of course, this is what I was investigating: transformation of conceptual learning by systematisation and concretisation. Experiencing my own hesitant conceptual transformation, at the same time as I was exploring the transformation of others, was necessarily troublesome but inspiring and this experience greatly contributed to my own personal understanding of the whole conceptual transformation process.

As an academic, teacher and leader, I am very aware that my learning is key to success of my students and also my colleagues. During this research I could not fail to learn about myself, my perspectives, my weaknesses and strengths. By the end, I recognised transformation, inner speech and critical thought everywhere: within the fiction I was reading, within my daily work, and also within my son's illness. For example, following in-depth discussion with my son about inner speech, he realised that the 'brain fog' he was experiencing due to his chronic fatigue affected his inner speech. This interrupted his conceptual thinking to inhibit his basic cognition making simple tasks of daily living, even talking, difficult. This over-simplified explanation for the odd symptoms of this complicated, enigmatic illness helped us to get through the dark days. In all, this 'bleeding' of thought across boundaries was useful to my research, as it stimulated new ways of thinking and seeing.

This was a transformative experience, akin to a long, troublesome gestation, a traumatic, exhausting labour, ended by a perspective-changing birth. Looking back, it is all so much easier on the other side. Would I have done anything differently? Yes, of course. Knowing what I know now, I could take a much more direct route to write this thesis. But this was a necessary learning journey and I made it, with help from my determined supervisors and the loving support of my family and friends. I feel very privileged and thankful to have been granted this transformative learning opportunity.

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APPENDICES

Chapter 2 Appendices

Appendix 2.1: Summary Tables of Known Threshold Concepts in EBP and Medical Biostatistics

Chapter 3 Appendices

Appendix 3.1: Interview Questions and Diagram Provided to Expert Participants

Appendix 3.2: Critical Thinking and Threshold Concept Definitions, and Visual Aids Provided to Participants

Appendix 3.3: Summary Table of Experts

Appendix 3.4: Specific Instructions Provided to Case Study Participants

Appendix 3.5: Example of the Jens Grid Used in Expert Interviews

Appendix 3.6: Original Ethics Approval Letter 2011 (Masters Research)

Appendix 3.7: Ethics Approval Letter 2014 (PhD Research)

Appendix 3.8: Ethics Modification Approval Letter (2016)

Appendix 3.9: Participant Information Statement and Consent Form

Chapter 4 Appendices

Appendix 4.1: Themes Arising from the Analysis

Appendix 4.2. EBP and Medical Biostatistics Conceptual Elements, Tables S4.1-4.11.

Appendix 2.1: Summary Tables of Known Threshold Concepts in EBP and Medical Biostatistics

Concept	Type of concept as proposed by published evidence	Strength of evidence	Main, higher quality sources *(chronologically)**
EBP - as process and as practice	Overarching threshold, way of practice or 'competence' or a way of thinking and practising (WTP)	Some evidence from educational research in undergraduate nursing and medicine. Varying strength of evidence found from various other healthcare, including occupational therapy, physiotherapy and optometry.	Quinnell & Thompson, 2010; Laibhen-Parkes, 2014; Alnahedh, Suttle, Alabdelmoneam & Jalbert 2015; Martindale, 2015; Nicola-Richmond, Pepin & Larkin, 2018. Noted: Links to professional practice, expertise, competency and identity.
EBP - as the stepped cycle	None specific. Possibly a step on way to clinical practice as EBP	Review of research suggests this is considered a step on the way to WTP, but perhaps not a TC in its own right.	Martindale, 2015; Nicola-Richmond et al, 2018.
Step 1: Asking clinical questions e.g. PICO	Possible threshold concept considering links to similar and necessary TC	Relevant concepts that impinge on this have been identified as threshold concepts, e.g. clinical skills, client-centred practice, communication skills and choice of keywords of information skills.	Tanner, 2011; Tucker, 2012; Nicola-Richmond et al, 2018; Wilkinson, 2018.
Step 2: Acquiring evidence e.g. Information Skills	Possibly an overarching concept or approach, or a complex threshold concept with many sub-threshold concepts/skills identified	Strong – weak evidence from many different types of studies, with data from experts, students and assessment. Very varied findings – possibly due to difference in expertise level and discipline/profession of participants studied.	Blackmore, 2010; Hofer, Townsend & Brunetti, 2012; Tucker, Weedman, Bruce & Edwards, 2014; Tucker, 2016. Noted: Links with academic writing.
Step 3: Critical Appraisal	Possible complex or over-arching TC	Considered by many EBP researchers across the healthcare spectrum to be the most difficult step of EBP. Identified as 'liminal', troublesome and transformative.	Johnston & Fineout-Overhold, 2006; Quinnell & Thompson 2010; Tucker, 2012; Tucker et al, 2014; Martindale, 2015. Noted: Links with academic writing.
Step 4: Apply e.g. Clinical significance	Identified as consisting of several threshold concepts	Difficult procedural skills are mastered and integrated into EBP practice. Clinical reasoning and decision-making most commonly identified as possible threshold concepts across the healthcare professions.	Wifstad, 2008; Quinnell & Thompson 2010; Martindale, 2015; Nicola-Richmond et al, 2018.
Step 5: Assess	None proposed	No specific evidence found for 'EBP', but strong evidence in professional practice (self-assessment, reflective practice) and in assessment in information skills. Sometimes presented as quality improvement.	Tucker, 2012; Martindale, 2015; Nicola-Richmond et al, 2018; Neve, 2019.

** Evidence published since 2016 has been added to this table (originally produced in 2016) where it supports the original findings.*

Medical Biostatistics	Type of concept suggested by published evidence	Strength of evidence	Main, higher quality sources *(chronologically)**
Sampling and / or uncertainty	Major/overarching threshold concept	Combined evidence is very strong from experts, students and assessments	Kennedy, 1998; Garfield & Ben-Zvi, 2007; Thompson, 2008; MacDougall, 2010; Quinnell & Thompson 2010; Norton, 2015; Wills, 2017.
Summary statistics	Threshold concept	Some evidence from students and experts /teachers. Troublesome for some UG students.	Bakker, 2004; Bulmer, O'Brien & Price, 2007; Quinnell & Thompson 2010; Wills, 2017.
Data distributions, incl. normal distribution	Threshold concept	Combined evidence is strong from experts, students, integrative	Dunne, Lowe & Ardington, 2003; Garfield & Ben-Zvi, 2007; R. Thompson, 2008; Quinnell & Thompson 2010; Wills, 2017.
Central limit theorem	Threshold concept	Often labelled the most difficult concept by students, teachers and experts, but evidence has not been corroborated.	Dunne et al, 2003; Quinnell & Thompson 2010; Wills, 2017.
Statistical Inference	Major/overarching threshold concept	Some evidence that the key ideas and threshold concepts re inference need to be integrated into a practice	Bulmer et al, 2007; Thompson, 2008; Quinnell & Thompson 2010; Wills, 2017.
Hypothesis generation	Threshold concept	Combined evidence is strong	Bulmer et al, 2007; Diamond, 2011; Meek & Jamieson 2012; Martindale, 2015; Wills, 2017
Statistical Significance, p values	Threshold	Combined evidence is strong, troublesome knowledge and language, transformative, integrative	Thompson, 2008; Quinnell & Thompson 2010; Diamond, 2011; Wills, 2017; Tam et al, 2018
Confidence intervals	Threshold	Combined evidence is strong	Quinnell & Thompson, 2010; Wills, 2017
Power and error	Thresholds – possibly more than one, integrated	Evidence from experts and learners that these are "difficult topics" that might be threshold in nature	Quinnell & Thompson 2010; Wills, 2017
Specific inferential tests or parts of tests or choice of tests	Probably not single thresholds, maybe require the integrative practice of several threshold concepts	Evidence not strong that these are individual thresholds, more evidence that they contain many thresholds and understanding these is part of the complex practice of statistics, involving decisions for practical implementation	Dunne et al, 2003; Bulmer et al, 2007; Thompson, 2008; Diamond, 2011; Khan, 2014.
Validity and bias	Possibly a major/overarching threshold concept	Variable evidence but cited as difficult or troublesome by experts, teachers and learners	Quinnell & Thompson, 2010; Wills, 2017.
Effect size	Threshold concept	Evidence not strong	Thompson, 2008.
External validity/clinical significance	Threshold concept, but with practical aspects	Difference between this and statistical significance was recognised by experts. Students found it troublesome.	Quinnell & Thompson 2010; Wills, 2017.
Probability distributions	Threshold concept	Variable evidence but cited as difficult or troublesome by experts, teachers and learners	Dunne et al, 2003; Quinnell & Thompson 2010; Diamond, 2011; Wills 2017

** Evidence published since 2016 has been added to this table (originally produced in 2016) where it supports the original findings.*

Appendix 3.1: Interview Questions and Diagram Provided to Expert Participants

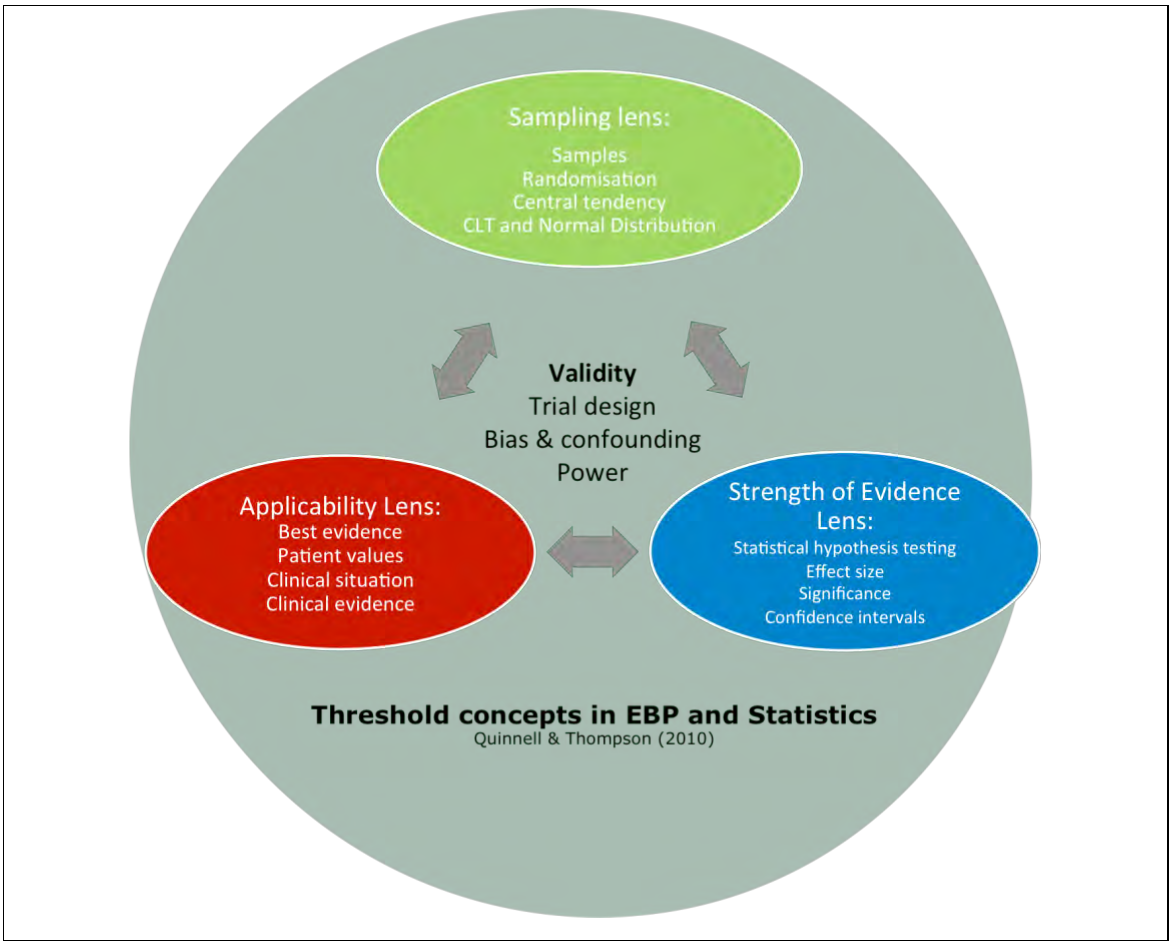
HREC HC14091 Interview Question Examples

Having heard about threshold concepts:

- Can you identify the key stumbling blocks in (student / your) learning in of statistics and/ or evidence-based practice in undergraduate medicine?
- Which of these would you consider to be the key **threshold concepts** for statistics and evidence-based practice?
- Can you see how these concepts might depend on knowing other basic concepts and how they also might link up as a network?
- Are you aware of how critical thinking skills or abilities might assist in this conceptual learning?
- Which specific skills or practices might be particularly useful in the journey towards the understanding of a threshold concept?
- What do you consider to be useful (teaching / learning activities/ support) for supporting/ the scaffolding of student learning of threshold concepts and critical learning?
- Do you have any ideas or theories regarding how critical thinking and conceptual learning might interact *practically*, or *intersect* in a student's actual *thinking processes*?
- Having considered all of this, do you think that critical thinking could be a type of Threshold skill, i.e. transformative, troublesome, irreversible and integrative?
    - If possible – please explain your reasoning
- Do you have any further ideas or contributions to share?

Version Date: 26.02.16

Diagram representing the overarching threshold concepts of sampling, strength of evidence and applicability lens. The main threshold knowledge concepts and procedural concepts are listed for each. Refined for teaching purposes from work published in (Quinnell & Thompson, 2010)



Appendix 3.2: Definitions and Visual Aids Provided to Participants

Characteristics of Threshold Concepts and definition of critical thinking skills

What are Threshold Concepts?

Threshold concepts are those key concepts that learners can get 'stuck at', but which they can't really do without if they progress to understanding a discipline area. Key characteristics of a threshold concept are given below with adaptations from:

- ***Transformative:*** *this is the most important characteristic. Understanding a threshold concept or gaining a threshold skill allows student to move onto higher-level thinking/ practice in this topic (it can be like an 'eureka effect'). Students can then think or practice in a more mature, discipline-like way (e.g. understand and think more like an engineer, etc).*
- ***Troublesome:*** *essential study skills or language can be troublesome, e.g. counter-intuitive, alien, difficult, etc,*
- ***Irreversible:*** *As understanding these concepts or gaining these skills is transformative, 'getting' them is therefore often irreversible and difficult to 'unlearn'.*
- ***Integrative:*** *Once understood or learned, the threshold concept / skill allows the student to integrate several different aspects of the subject matter / process that previously did not seem to fit together.*
- ***Bounded:*** *Some key threshold concepts appear to delineate their discipline conceptual space. Similarly, threshold skills can appear to be discipline specific. For instance, if you learn how to do a critical appraisal in one discipline, you might need assistance to see how to transfer and use this skill in a different discipline.*

(Meyer & Land, 2003)

What critical thinking skills are used in conceptual learning?

When we tackle learning difficult and troublesome concepts, it is likely that we are using our **critical thinking skills** in this learning process.

Consensus List of Critical Thinking Cognitive Skills And Sub-Skills

1. **Interpretation:** Categorization, Decoding Significance, Clarifying Meaning
2. **Analysis:** Examining Ideas, Identifying Arguments, Analyzing Arguments
3. **Evaluation:** Assessing Claims, Assessing Arguments
4. **Inference:** Querying Evidence, Conjecturing Alternatives, Drawing Conclusions
5. **Explanation:** Stating Results, Justifying Procedures, Presenting Arguments
6. **Self-Regulation:** Self-examination, Self-correction (e.g. reflective practice)

(Facione, 1990)

Appendix 3.3: Summary Table of Expert Participants

Pair	Job title	Expertise (plus years of teaching)	Qualifications
-	Clinician, Anaesthesia	Anaesthesiology, clinical, teaching and research Medical statistics teaching and curriculum development (undergraduate and postgraduate) (35+ years)	MBBS, Fellowship of Australian and New Zealand College of Anaesthetists
1	Senior lecturer, Biostatistics	Teaching and developing content: biostatistics and epidemiology on public health master's courses. (15-20 years teaching)	BSc, MPH, PhD
1	Senior lecturer, Clinician	Clinical teaching and research, Medicine program curriculum design development and convening. (30 years clinical teaching, professional adult training experience, 18 years university teaching)	MBBCh, MBA, MA(Hons) MMed(Clin Epi), FCHSM PhD
2	Clinician, Anaesthesia	Anaesthesiology and Hyperbaric medicine, clinical, teaching and research Medical statistics teaching and curriculum development (undergraduate and postgraduate) (35+ years)	MBBS, Fellowship of Australian and New Zealand College of Anaesthetists
2	Clinician, Rheumatology	Clinical teaching and research, Medicine program curriculum design development and convening. (~20 years clinical teaching)	MBBS, MMedEd, FRACP, AFANZAHPE
3	Professor, Biostatistics	Biostatistical researcher. Teaching and developing content: biostatistics and epidemiology on public health master's courses (~20 years teaching)	BSc, MBiostats, PhD
3	Associate Professor, Medical Education	Biostatistics: teacher, researcher Research area: medical program assessment and selection (~20 years teaching)	BSc, MBiostats, PhD

Appendix 3.4: Instructions Provided to Case Study Participants

2016 Research Project: ***A critical intersection: an exploration of undergraduate medical students' critical thinking within threshold concept liminal spaces – a Vygotskian perspective*****.**
March 2016, Dr Rachel Thompson, OME, UNSW Medicine.

This research study aims to explore how critical thinking assists in the transformational conceptual learning of threshold concepts.

Threshold concepts are those **troublesome, but transformative concepts** that tend to define and demarcate the specialist knowledge of discipline areas. These are the concepts that we usually have the most trouble with in our learning, and where as a learner you can get 'stuck' and can't move forwards to learn more in a topic.

These **threshold concepts** are often:

- **Transformative** – in that the learner will change identity or shift their view of the subject substantially. There might be an emotional change and rarely there may be a full 'eureka' or 'light-bulb' moment.
- **Troublesome knowledge** – the knowledge is problematic and difficult to comprehend. This might be due to the type of knowledge it contains. It can be "alien or counterintuitive" knowledge that is inherently difficult for the learner by challenging current knowledge or cultural understandings and can even seem incoherent.
- **Irreversible** – in the sense that the understanding, once experienced, is hard to forget or unlearn (such as on learning to ride a bike).
- **Integrative** – the understanding of a particular concept can reveal interrelated understandings, for instance other concepts appear more understandable or connected, or a learner may be able to understand another related concept more easily once they 'get' a threshold concept.
- **Bounded** – sometimes, but not always, these concepts and their related concepts denote boundaries of discipline-based knowledge and / or the frontiers of particular academic discourses.

Your participation involves:
1. Initial **interview** in March/ April
2. **Recording** your learning experiences during the year (see below)
3. Attend 2 or 3 **follow-up interviews** during this year
4. **Final interview** or focus group in November

Recording your learning experiences:
- As a case study volunteer, we would like you to record your learning experiences in a '**learning journal**' for learning in **evidence-based practice** and **statistics**.
- Mostly this will be recording the learning that you encounter in QMP in Phase 1 courses, Phase 2 coursework or ILP. If you are learning in clinical environments, then you might encounter threshold concept learning in these environments also.

What to record:

- Specifically, we want to know about **what happens to your *thinking*** when you get 'stuck' and struggle and then hopefully gain understanding: what helped you, what hindered your learning, and what might have been useful in retrospect.

How and when to make a recording:

- If you get stuck, struggle with a concept, or have a 'eureka' moment and/ or finally 'get it', take a moment to record what has happened and what you think helped you with this conceptual understanding.
- See the **prompt questions** provided below to help you reflect on the learning.

How to record a learning journal:

1. You may record your reflections as any/ all of the following *electronic* formats:
    a. Audio (mp3/4 formats)
    b. Video clips
    c. Concept-maps or diagrams or images
    d. Written text or lists / bullet points
2. We suggest you keep these recordings in one folder named something like: "**Research project 2016_Learning_journal**" in a secure place and back this up.
3. Label each recording as follows: "**Learning Journal_[your initials]_ [DDMMYY]**"

When to send recordings in:

- A simple fortnightly email request requesting journal updates will be sent to you from Dr Thompson (during semester time only).
- Please check your learning journal folder, read through/ listen to all recent recordings (since the last email). Edit if appropriate/ add anything else that is relevant. Then send these recordings to Dr Thompson (via email).

Further interviews:

- You will be emailed to ask to attend further 2 or 3 individual or small group interviews during semester time in 2016.
- The interviews will aim to find out more about your learning experiences and discuss your learning progress in these topics.

Prompt Questions (for your journal recordings):

1. *Date and time*
2. *What topic / particular concept(s) are you currently reflecting upon?*
3. *Give a general description of the concept(s) and what happened to your learning.*
4. *Did you gain understanding or are you still not certain about this concept?*
5. *What do you now understand about this concept? Explain or map this out.*
6. *Can you pinpoint any particular* ***critical thinking skills*** *that you might have used to understand this concept, specifically:* ***abstraction****,* ***synthesis, judgement, analysis, appraisal, evaluation, decision-making, comprehension, application****?*
7. *Did anything else help your learning of this concept?*
    a. *Was there anything that someone said or did to explain the concept?*
    b. *A particular example or learning activity?*
    c. *Any particular resource (book/ paper/ lecture) that helped?*
8. *Reflecting on your emotions in this learning:*
    a. *How did you / do you feel about this learning experience?*
    b. *Any particular emotions that arose then?*
    c. *How do you feel about it now?*
9. *Please record anything else you think is important about your struggle to learn this concept.*

Appendix 3.5: Example of the 'Jens Grid' Used in Expert Interviews

Threshold concepts - Characteristics	Statistics	EBP
Teaching	Student learning	Own learning
Specific TC discussed	Networks discussed	Liminal Space issues
Teaching resources or ideas	Critical thinking skills	CT specific to TC?
Other/Notes		

Appendix 3.6: Original Ethics Approval Letter 2011 (Master's Research)

UNSW

Medical and Community Human Research Ethics Advisory Panel

6 September 2011

Dr Rachel Thompson
Medical Education and Student Office
Faculty of Medicine
UNSW

Reference: *"An investigation of how and why undergraduate medical students at UNSW are supported in learning to become critical practitioners."*
Reference Number: 2011-7-25
Reference: *Thompson, Scicluna*

At its meeting of 4 July 2011 the Medical and Community Human Research Ethics Advisory Panel was satisfied that this project is of minimal ethical impact and meets the requirements as set out in the National Statement on Ethical Conduct in Human Research. Having taken into account the advice of the Panel, the Deputy Vice-Chancellor (Research) has approved the project to proceed.

This approval is valid for 12 months from the date of the meeting. Please provide a copy of this letter to your Head of School.

Yours sincerely

A/Professor Heather Worth
Medical and Community Human Research Ethics Advisory Panel

THE UNIVERSITY OF NEW SOUTH WALES
UNSW SYDNEY NSW 2052 AUSTRALIA
Tel: +61(2) 9385 2517, Fax: +61(2) 9313 6185
Email: sphcm@unsw.edu.au
Web: www.sphcm.med.unsw.edu.au
ABN 57 195 873 179
CRICOS Provider No. 00098G

Appendix 3.7: Ethics Approval Letter 2014 (PhD Research)

UNSW
AUSTRALIA

HUMAN RESEARCH ETHICS COMMITTEE (HREC)

01-Jul-2014
Dr Matthew Clarke
Sydney NSW 2052

Dear Dr Clarke,

HREC Ref: # **HC14091**
An investigation of how and why undergraduate medical students at UNSW are supported in learning to become critical practitioners.

The Human Research Ethics Committee considered the above protocol at its meeting held on 01-Jul-2014 and is pleased to advise it is satisfied that this protocol meets the requirements as set out in the National Statement on Ethical Conduct in Human Research*. Having taken into account the advice of the Committee, the Deputy Vice-Chancellor (Research) has approved the project to proceed.
Would you please note:-

- approval is valid from 01-Jul-2014 to 01-Jul-2019;
- you will be required to provide annual reports on the studys progress to the HREC, as recommended by the National Statement;
- you are required to immediately report to the Ethics Secretariat anything which might warrant review of ethical approval of the protocol (National Statement 3.3.22, 5.5.7: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf) including:
  - serious or unexpected outcomes experienced by research participants (using the Serious Adverse Event proforma on the University website at http://research.unsw.edu.au/human-ethics-forms-and-proformas ;
  - proposed changes in the protocol; and
  - unforeseen events or new information (eg. from other studies) that might affect continued ethical acceptability of the project or may indicate the need for amendments to the protocol;
- any modifications to the project must have prior written approval and be ratified by any other relevant Human Research Ethics Committee, as appropriate;
- if there are implantable devices, the researcher must establish a system for tracking the

participants with implantable devices for the lifetime of the device (with consent) and report any device incidents to the TGA;

- if the research project is discontinued before the expected date of completion, the researcher is required to inform the HREC and other relevant institutions (and where possible, research participants), giving reasons. For multi-site research, or where there has been multiple ethical review, the researcher must advise how this will be communicated before the research begins (National Statement 3.3.22, 5.5.7: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf);

- consent forms are to be retained within the archives of the EDUC - School of Education and made available to the Committee upon request.

1. All approval letters must be forwarded onto the UNSW committee prior to commencing at any new sites. Please confirm that this will happen.

2. In order to ensure that the focus groups are manageable and as per UNSW standard practice, please ensure that the numbers for each group are limited to no more than 10 participants per group.

Sincerely,

Professor Heather Worth
Presiding Member
Human Research Ethics Committee

* http://www.nhmrc.gov.au

Appendix 3.8: Ethics Modification Approval Letter (2016)

Human Research Ethics Committee (HREC)
The University of New South Wales
UNSW Sydney, NSW, Australia, 2052
E: humanethics@unsw.edu.au
W:https://research.unsw.edu.au/human-research-ethics-home

02-Mar-2016

Dear Mr Michael Michell,

Project Title	An investigation of how and why undergraduate medical students at UNSW are supported in learning to become critical practitioners.
HC No	HC14091
Re	Modification request dated 26.02.2016 seeking a large number of modifications due to a refocus in the research, as outlined in the attachment.

The modification to this project was **approved** by the **HREC Executive** on 01-Mar-2016.

If this project is a multicentre project you must forward a copy of this letter to all Investigators at other sites for their records.

Please note that all requirements and conditions of the original ethical approval for this project still apply.

Should you require any further information, please contact the Ethics Administrator at:

E: humanethics@unsw.edu.au
W:https://research.unsw.edu.au/human-research-ethics-home

The UNSW HREC Executive wishes you every continued success in your research.

Kind Regards

Professor Heather Worth
HREC Presiding Chairperson

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) *National Statement on Ethical Conduct in Human Research (2007)*. The processes used by this HREC to review multi-centre research proposals have been certified by the National Health and Medical Research Council.

Appendix 3.9: Participant Information Statement and Consent Form

Combined for the appendix (originally separate documents provided to each participant group)

UNSW School of Education Faculty of Arts and Social Sciences	UNSW AUSTRALIA
PARTICIPANT INFORMATION STATEMENT AND CONSENT FORM EXPERTS/MEDICAL STUDENTS - FOCUS GROUPS/MEDICAL STUDENTS - CASE STUDIES A Critical Intersection: An Exploration of Undergraduate Medical Students' Critical Thinking within Threshold Concept Liminal Spaces – a Vygotskian Perspective. Dr Michael Michell	

The study is being carried out by the following researchers:		
Role	**Name**	**Organisation**
Chief Investigator	Dr Michael Michell	School of Education, FASS, UNSW
Co-Investigator/s	Dr Rachel Thompson Dr Helen Scicluna	Office of Medical Education, UNSW Medicine
Student Investigator/s	Dr Rachel Thompson is conducting this study for a doctoral degree at UNSW. This will take place under the supervision of Dr Michael Michell and A/Prof Noel Whitaker	Office of Medical Education, UNSW Medicine; School of Education, FASS, UNSW; and Faculty of Science, UNSW.
Research Funder	N/A	

What is the research study about?

You are invited to take part in this research study. You have been invited because you are a student enrolled in the undergraduate medicine program at UNSW.

To participate in this project you need to meet the following inclusion criteria:

Recruitment of Experts:

- Be a teaching academic in statistics, clinical medicine or medical science at UNSW.
- Be available for interview in March - April 2016.

Medical Students:

- Be enrolled as a Phase 1-3 student in medicine at UNSW during 2016.

Focus group:

- Be available for group interview at University during 2016.

Case study:

- Be available for interview and / or focus group interviews March to November 2016.

- Be prepared to keep a reflective journal about your learning experiences of specific 'threshold concepts' in encountered in the curriculum for statistics and evidence-based practice.

ALL:

The research study is aiming explore how **critical thinking** assists in the transformational conceptual learning of **threshold concepts**. Threshold concepts are those troublesome, transformative concepts that tend to define and demarcate the specialist knowledge of discipline areas. These are the concepts that we usually have the most trouble with in our learning, and where students can get 'stuck' and can't move onwards. This is because these concepts are often:

- **Transformative** – in that the learner will change identity or shift their view of the subject substantially. There might be an emotional change and rarely there may be a full 'eureka' moment.
- **Troublesome knowledge** – the knowledge is problematic and difficult to comprehend. This might be due to the type of knowledge it contains. It can be "alien or counterintuitive" knowledge that is inherently difficult for the learner by challenging current knowledge or cultural understandings and can even seem incoherent.
- **Irreversible** – in the sense that the understanding, once experienced, is hard to forget or unlearn (such as on learning to ride a bike).
- **Integrative** – the understanding of a particular concept can reveal interrelated understandings, for instance other concepts appear more understandable or connected, or a learner may be able to understand another related concept more easily once they 'get' a threshold concept.
- **Bounded** – sometimes, but not always, these concepts and their related concepts denote boundaries of discipline-based knowledge and / or the frontiers of particular academic discourses.

Expert version: Your role in this research will be to help to identify the key threshold concepts in statistics and evidence-based practice as encountered by students in our UNSW medicine program curriculum and to examine the critical thinking skills that might assist students in 'crossing' this threshold to understanding.

The researchers will also be recruiting medical students in a case series across the program to follow-up their learning experiences over a university year. These students will record specific occurrences when they encounter the identified 'threshold concepts' and will specifically detail how their critical thinking skills were employed in that very specific transformational moment of struggling with and then finally understanding the concept fully.

Focus group version: Your role in this research will be to discuss the possible key threshold concepts in statistics and evidence-based practice as encountered by students in our UNSW medicine program curriculum and to examine the critical thinking skills that might assist students in 'crossing' this threshold to understanding.

The researchers will also be recruiting medical students in a case series across the program to follow-up their learning experiences over a university year. These students will record specific occurrences when they encounter the identified 'threshold concepts' and will specifically detail how their critical thinking skills were employed in that very specific transformational moment of struggling with and then finally understanding the concept fully. There is no reason why you should not participate in this part of the research as well.

Case study version: There are various elements to the study – including what is known as **a case series study**. This is the part of the study you are being asked to take part in. For this case series study the researchers will follow volunteer medical students over the medical program year to find out about their learning experiences. Your role in this research will be to help to examine the critical thinking skills that might assist students in 'crossing' the threshold to understanding for these particular concepts.

ALL:

Do I have to take part in this research study?

Participation in this research study is voluntary. If you don't wish to take part, you don't have to. Your decision will not affect your relationship with The University of New South Wales Office of Medical Education, the School of Education, or the UNSW medicine program.

This Participant Information Statement and Consent Form tells you about the research study. It explains the research tasks involved. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative or friend.

If you decide you want to take part in the research study, you will be asked to:

- Sign the consent form;
- Keep a copy of this Participant Information Statement;
- Attend an initial interview (as described below);
- Keep a 'learning journal' as (described below);
- Attend further individual or group interviews/ focus groups as requested during the year.

What does participation in this research require, and are there any risks involved?

Expert version:

If you decide to take part in the research study, we will arrange a convenient time for a face-to-face interview (lasting approx. 60 mins). Another colleague will be interviewed at the same time – this is a 'paired' interview where discussion around the interview topics will be encouraged.

The interview will be loosely structured as it aims to draw out the both interviewees understanding of threshold concepts in statistics / evidence-based practice. In addition, the interviewer will ask you both about how you consider that critical thinking assists the hypothetical 'learner' in moments of transformational conceptual learning.

These interviews will take place in a quiet, private meeting room in Wallace Wurth or Lowy Building on UNSW Kensington Campus (exact location to be confirmed).

Focus group version:

If you decide to take part in the research study, we will arrange a convenient time for a focus group interview (lasting approx. 60 - 90mins). Two researchers will be present to guide and record a discussion around the interview topics.

The focus group will take place in a quiet, private meeting room in Wallace Wurth or Lowy Building on UNSW Kensington Campus (exact location to be confirmed).

Case study version:

If you decide to take part in the research study, we will arrange a convenient time for a face-to-face interview. The research team will contact you for intermittent follow-up individual, group or focus group interviews during the medical program year (maximum of 4 interviews).

You will also be asked to record specific details in an electronic 'learning journal' regarding your experiences of encountering identified 'threshold concepts' in your usual study practice in the medical curriculum. Specific detail should be noted about how your critical thinking skills were employed in the very particular transformational moment of struggling with and then finally understanding a threshold concept fully. You will be able to use several options for recording this reflective material: written text, voice and/or video recording, and creation of concept maps. Once a fortnight during semester time, you will receive an email from the research team, requesting an update of your journal record. You are free to decide what you send in to the team, for each of these requests.

The initial interview with a member of the research team will take approximately 60 minutes. The interviewer will confirm your understanding of the research study and what is being asked of you and, if you agree to participate, he/she will obtain written consent (on this form). He/she will then go on to ask you a few open-ended questions to discuss your current understanding of these threshold concepts and how you currently use your critical thinking skills in your learning and studying.

The follow-up interviews will be run in a similar manner but will focus on discussing the information that you have provided via your journal updates and to compare what you have found with data from all participants and the on-going analysis. Mostly these will be individual interviews, but you may be asked if you are comfortable with taking part in a group interview (maximum of 2 other students). If you prefer not to take part in a group interview, then an individual interview will be arranged at your convenience.

Please note that some of these follow-up interviews may become educational in nature as you discuss with the interviewer your understanding of the threshold concepts and critical thinking skills. This is considered an important part of the research, but if at any point you feel uncomfortable in this situation you can stop the interview completely or request a change of topic. Also, you can request the relevant recording or notes to be deleted and not be used in the study research. (See more on this below).

You may be asked to attend a focus group interview (lasting approx. 60 - 90mins). Two researchers will be present to guide and record a discussion around the interview topics.

All these interviews will take place in a quiet, private meeting room in Wallace Wurth or Lowy Building on UNSW Kensington Campus (exact location to be confirmed).

ALL:

Will I be paid to participate in this project?
There are no costs associated with participating in this research study, nor will you be paid.

What are the possible benefits to participation?
While ultimately the information will be used to improve the UNSW Medicine program, we cannot and do not guarantee or promise that you will receive any benefits (educational or otherwise) from this study.

What will happen to information about me?
By signing the consent form you consent to the research team collecting and using information about you for the research study. We will keep your data for five years and then destroyed/deleted.

Audio files and transcripts of interviews will be maintained in a locked and password-protected environment in the Office of Medical Education and will not be used for any other purpose than this study. Your information will only be used for the purpose of this research study and it will only be disclosed with your permission

It is anticipated that the results of this research study will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be published, in a way that we protect your identity. However, although every effort will be made to protect your identity, there is a small risk that you might be identifiable in publications by someone who knows you well, due to the nature of the study and/or the results.

You have the right to request access to the information about you that is collected and stored by the research team. You also have the right to request that any information with which you disagree be corrected. You can do this by contacting a member of the research team.

How and when will I find out what the results of the research study are?
You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback at any time. General feedback will be sent via email to all participants. You will receive this feedback after the study is finished.

What if I want to withdraw from the research study?
If you do consent to participate, you may withdraw at any time. If you do withdraw, you will be asked to complete and sign the 'Withdrawal of Consent Form', which is provided at the end of this document. Alternatively, you can ring the research team and tell them you no longer want to participate.

If you decide to withdraw from the study, we will not collect any more information from you. Please let us know at the time when you withdraw what you would like us to do with the information we have collected about you up to that point. If you wish your information will be removed from our study records and will not be included in the study results, up to the point that we have analysed and published the results.

You are free to stop the interview at any time or to refuse to answer any of the questions. However, for a group discussion, it will not be possible to withdraw your individual comments from our records once the group has started.

If you take part in a focus group, you are free to stop participating at any stage or to refuse to answer any of the questions. However, it will not be possible to withdraw your individual comments from our records once the group has started, as it is a group discussion.

What should I do if I have further questions about my involvement in the research study?

The person you may need to contact will depend on the nature of your query. If you want any further information concerning this project or if you have any problems, which may be related to your involvement in the project, you can contact the following member/s of the research team:

Research Team Contact

Name	Dr Rachel Thompson
Position	Senior Lecturer, Office of Medical Education
Telephone	02 9385 8038 or 0407 706001
Email	rachelt@unsw.edu.au

What if I have a complaint or any concerns about the research study?

If you have any complaints about any aspect of the project, the way it is being conducted, then you may contact:

Complaints Contact

Position	Human Research Ethics Coordinator
Telephone	02 9385 6222
Email	humanethics@unsw.edu.au
HC Reference Number	HC14091

Consent Form – Participant providing own consent

Declaration by the participant

- I have read the Participant Information Sheet or someone has read it to me in a language that I understand;
- I understand the purposes, study tasks and risks of the research described in the project;
- I have had an opportunity to ask questions and I am satisfied with the answers I have received;
- I freely agree to participate in this research study as described and understand that I am free to withdraw at any time during the project and withdrawal will not affect my relationship with any of the named organisations and/or research team members;
- I understand that I will be given a signed copy of this document to keep;

Participant Signature

Name of Participant (please print)	
Signature of Research Participant	
Date	

Declaration by Researcher*

- I have given a verbal explanation of the research study, its study activities and risks and I believe that the participant has understood that explanation.

Researcher Signature*

Name of Researcher (please print)	
Signature of Researcher	
Date	

+**An appropriately qualified member of the research team must provide the explanation of, and information concerning the research study.**

Note: All parties signing the consent section must date their own signature.

Form for Withdrawal of Participation

I wish to **WITHDRAW** my consent to participate in the research proposal described above and understand that such withdrawal **WILL NOT** affect my relationship with The University of New South Wales, , the Office of Medical Education, the School of Education, or the UNSW medicine program.

Participant Signature

Name of Participant (please print)	
Signature of Research Participant	
Date	

The section for Withdrawal of Participation should be forwarded to:

CI Name:	Dr Michael Michell
Email:	m.michell@unsw.edu.au
Phone:	02 9385 1956
Postal Address:	School of Education, University of New South Wales University of New South Wales UNSW Sydney NSW 2052 AUSTRALIA

Appendix 4.1: Themes Arising from the Analysis

Thematic analysis around this topic across all participants revealed the following themes around: discipline, conceptual learning, threshold concepts, conceptual networking and critical thinking skills. The themes (asterisked below) of critical thinking skills and key threshold concept characteristics that were provided to participants (i.e. main themes originating from the Consensus Document on Critical Thinking (Facione, 1990) and threshold concept characteristics from the TCF) were added as a primer to NVIVO, with others added as the analysis progressed. Themes for other topics were added as they were revealed through successive the abductive data analysis process.

Discipline themes:

- Clinical topic
- EBP topic
- Statistics
- Other topics (including medical science, non-medical (e.g. school subjects such as mathematics, physics)

Conceptual learning themes:

- Ways of teaching/understanding:
    - Analogy/metaphor, Demonstration and/or instruction, Scaffolding, Scenario/Narrative based learning, Teaching
- Learning styles/ways of learning:
    - Auditory learning, Visual learning, Kinaesthetic learning, Mathematical learning, Writing/ reading as learning, Peer learning, Rote learning or memorisation or surface learning, Student learning, subcat: Repetition or Practice
- Concepts:
    - Everyday /spontaneous concepts, Non-spontaneous scientific concepts,
- Ways of thinking:
    - Subconscious thinking
    - Forgetting concepts
    - Critical thinking (CT) and its sub-categories – listed further below
- Outcomes:
    - Understanding
- Adjunct/hindrances:
    - Motivation and engagement
    - Struggle
    - Trigger for deeper learning
        - Relevance/importance
    - Confidence
    - Examples in L&T
    - Peer learning

Critical thinking themes:

(includes themes from definitions given to participants)*

- Abstraction

- Analysis or evaluation*:
    - Analysing arguments*
    - Assessing arguments*
    - Assessing claims*
    - Examining ideas*
- Comprehension
- Decision-making
- Definition of CT
- Explanation*:
    - Presenting an argument
- Focus
- Inference*:
    - Application
    - Synthesis
- Interpretation*:
    - "Making sense of a topic" (Clarifying meaning*)
    - Categorisation*
    - Simplification/Breaking down of elements (Decoding significance*)
- Judgment
- Mapping or creating own pathways
- Problem-solving
- Reflective practice:
    - Self-questioning/Interrogation*

Themes arising in the data re threshold concepts and transformation:
(includes themes from the accepted TCF definition)*

- Liminal space
- Perspective or ontological shift
- Threshold concept characteristic:
    - Difficult or troublesome concept*, Counterintuitive*, Difficult or troublesome language*, Discipline bounded*, Integrative*, Irreversible*, Network of concepts, Transformative*
- Threshold concept identification
- Threshold concept vs Threshold Skill
- Transformations

Conceptual network themes:

- Network of concepts (under "Threshold concepts" theme heading)
- Mapping or creating own pathways (under "Critical Thinking" theme heading).
- Integration: this threshold concept definition term (provided to participants) was used alongside these two new themes in the abductive analysis for coding interview and other data.

Appendix 4.2. EBP and Medical Biostatistics Conceptual Elements

Key and References

Abbreviations:

K: Knowledge

A: Application to practice

WTP: Way of thinking and practising, see: McCune and Hounsell (2005)

TC: Threshold concept

Core EBP competencies:

See EBP core competencies as defined by consensus study and listed in the supplementary material of Albarqouni et al., 2018.

Models used:

TCF: Threshold Concept Framework (based on: (Meyer & Land, 2003)

ITCK: Integrated Threshold Concept Knowledge model (Meyer & Timmermans, 2016)

K-S-M with TC model: Combined Knowledge-Strategies-Model framework with threshold concepts (TC) (Rountree, Robins, & Rountree, 2013, p. 279)

Tucker Model of Search Expertise: Based on Information Literacy PhD research of Masters level information skills training (Tucker, 2012, p. 253)

D&D: Dreyfus & Dreyfus 5-level expertise model (Dreyfus & Dreyfus, 2005)

Blooms: Revised Blooms Taxonomy, updated framework (Krathwohl, 2002)

Q&T: My previous research in Quinnell and Thompson (Quinnell & Thompson, 2010) leading to my original model of EBP and Biostats as a network of TC (see Figure 1.3, Appendix 3.1)

*Denotes this concept was considered a TC in my published and non-published associated research from 2010-2016.

Table S4.1 Exploration of conceptual elements, learning and expertise: ***EBP as a Practice***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
EBP as Clinical Practice Perspective *Putting evidence into practice within the clinical environment as a practising clinician, using an evidence-based approach.* *Using EBP cycle automatically and seamlessly with patient care and management.*	Overarching TC as practice Expert Level; WTP is vital *Identity as a fully-fledged EBP practitioner is recognised and a WTP - puts EBP knowledge and skills into practice holistically within routine clinical practice.* • Transformational, fully integrative. • WTP: involves a particular way of thinking and practising that results from a fusion of many TC and strategies/skills and models. • However, this is only part of the full identity of the 'best-practice' clinician. • EBP overarching core competency is basically the definition of EBP- so this is the fundamental practice for clinicians: 0.0 "Understand evidence-based practice (EBP) defined as the integration of the best research evidence with clinical expertise and patient's unique values and circumstances." (Albarqouni et al., 2018)	• More mature students & clinical experts keen to identify this as the major integrative threshold concept in its own right, bringing together many concepts and skills with a way of practising; an essential threshold in becoming an effective, safe and evidence-based practitioner. • Specifically: transformational, troublesome, integrative • Data analysis suggests this is the integration of multiple concepts and skills for putting EBP into practice.	Literature: Well supported in the literature now across the healthcare professions. In more recent literature this is often mentioned as a holistic approach to practice. Martindale: Yes: considers this a WTP – Over-arching and integrative, p. 394. Clear findings about need for learners to understand the difference between researching evidence for clinical practice and for research practice. Transformational element to this realisation. Other research: Medicine, Nursing and Physiotherapy/Occupational Therapy and Optometry etc – yes – all consider this as a troublesome complex practice and that understanding is integrative of core concepts/ competencies/ skills. Core EBP competencies research (Albarqouni et al., 2018): Top level "Clinical expertise required to *integrate* evidence with patient values and circumstances." Detail emphasises the EBP definition but also how this intersects with the 3 domains of EBP. Includes recognition of "the rationale for EBP" and understanding the difference between using research for clinical decision-making vs for conducting research. The sub-competencies are expected to be explained or mentioned to learners with practice in implementing the whole 5 EBP steps together.	TCF: YES - *more* than a TC = "overarching" With ITCK approach: positive responses derived from all types of participant student, teacher experts, professional experts K-S-M: Data agrees with this model in terms of this being an integrated/complex TC where learner gains expertise through the knowledge (multiple concepts), learning and using the practice strategies and developing their own internalised models of practice to make this achievable quickly and easily in the real-world situation. Tucker: Integration of TC is similar to this model but at a higher level, as it contains her search model of expertise. Many TC that are fused. Is this a mega TC? A fusion of fused TC? D&D: Definitely expert level for full effect of competent, automatised practice. Blooms: Highest level in practice: metacognitive knowledge dimension. Q&T: application of evidence to patient in the health environment as a practitioner is the overarching 'TC of Application to Practice' with Clinical significance as a key TC for students to get to this stage.

Table S4.2. Exploration of conceptual elements, learning and expertise: ***the EBP Cycle as a whole process***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
EBP elements as a whole cycle process *Understanding that EBP is more than a simple tool but can be applied by practitioner to all healthcare practice.*	**A holistic framework/tool for use in healthcare practice.** **Expert level incorporates this into clinical WTP (see above)** **Competent Level not quite WTP** *Students start to see how all the steps work together as a cycle of practice.* • Rationale behind the use of the process as a whole was deemed **troublesome** but also **transformative** for some learners. • Almost at level of **WTP -** the student is on way to full practice if can complete a full cycle. But- needs more clinical practice and experience to really be able to use this as part of EBP WTP. • Acceptance that this is a practical ***tool*** not knowledge or a definition.	• All students and experts identified at least one of the 5 EBP steps as a **TC**. • All 5 steps identified as **troublesome** and **complex** separately. • Expert 1 thought that *accepting* these as a framework, understanding the steps together, could be a threshold concept in itself. • Considered as **complex TC** - but linked or networked concepts, rather than simple or single concepts. • Requiring other skills and competencies such as communication skills (good history taking etc) and seeing it as a whole practice to put it fully into full competent practice.	**Literature:** Martindale: almost seen a conceptual step on the way to WTP and overarching concept. More recent research in medicine and nursing mostly have similar view to Martindale. **Core EBP competencies:** In this study, this was viewed as *a way of practising*. Positioned at top of the competencies list as part of the – section (0.01) headed "recognising the rationale for EBP"	**TCF:** Meets all the key characteristics. **ITCK:** positive responses derived from all types of participant student, teacher experts, professional experts **K-S-M:** Agrees with this model in terms of the integrating of TC through knowledge, strategies and models. **Tucker model:** integration of TC required here -so concept fusion might be part of this. Hence, similar to her model but must be at a higher level of EBP practice, as it contains the concepts of this search model of expertise for information literacy. **D&D:** This could be the first major transformational step to integrate practice into holistic practitioner. So, this suggests that this could indicate that using EBP at a competent level if able to perform the 5-steps of EBP competently but not have that full practitioner view as yet. **Blooms:** Using the procedural knowledge in practice, develops the metacognitive. **Q&T:** This is just beyond the TC of clinical significance in my model – i.e. see the importance of adapting evidence into practice and how this is different to knowledge held. This is understanding that application to practice is the reason for EBP.

Table S4.3 Exploration of conceptual elements, learning and expertise: ***EBP Cycle Individual Steps – Step 1: Asking***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• Asking *Step 1 of the EBP cycle: "Asking"* Asking clinical questions *Being able to identify the key components of the patient's problem and complex context and create a sensible clinical question for use in further investigation.* *IN EBP cycle, usually structured using PICO format.* *Parallel in research practice is learning how to ask a good research question.*	Troublesome capability, not always transformative. • Skill-heavy conceptual domain, several concepts involved here. • Communication skills key here for the real-life situation as have to work with patient to find their problem, needs and situation for the defining of their clinical question.	• Novice learners found this particularly troublesome - e.g. first- and second-year journal remarks. • Mature students seemed to have forgotten this element of the cycle – maybe had already become automatic. • Experts identified this as troublesome and transformative early on for some students, but not for others. • Transliminal concept within this area is probably "the Patient." Very engaging element of the early learner's experience and remains so for early competent clinical learners. Not a discrete TC as such, but students mentioned this as a really powerful, interesting part of their learning. Can be troublesome but not really transformative or a TC. Students mostly come into medicine to 'see and treat' patients so this is a common lure to get them interested in learning.	Literature: Interesting area as overlaps with communication and clinical skills literature. Complex knowledge and skills to learn here – acknowledged as difficult area and can cause struggle and disengagement in students. Core EBP competencies: 1.0 Ask competency. Identifies 3 main sub-competencies: 1.1 Explain the difference between the types of questions that cannot be answered by research (background questions) and those that can (foreground questions). 1.2. Identify different types of clinical questions, such as questions about treatment, diagnosis, prognosis, and aetiology. 1.3 Convert clinical questions into structured, answerable clinical questions using PICO.	TCF: Possibly TC here for some/most students, but not necessarily acknowledged as transformative. If viewed as "taking a patient history" several students said this was transformative and troublesome and required lots of practice to "get right" and become competent at. ITCK: most but not all participants found this had TC characteristics. K-S-M: Knowledge, strategies and models utilised in this learning and practice, especially in authentic situation (e.g. strategy could be the identification of clinical question type, models would be history taking models and PICO). Tucker model: From my data there doesn't appear to be a clear concept fusion happening here, so maybe this is looser conceptual web and not an over-arching TC. D&D: Students and experts were clear that definitely need both knowledge and practice of the related skills to gain expertise. My student participants became competent during clinical years but found the early learning challenging as it was hard to use authentically. Blooms: High level cognitive and knowledge skills needed here for full expertise. Student's knowledge and skills originally are both low. Practice in questioning patients and formulating questions helps. Q&T: Yes – Info skills seen as integrated TC complex from the start.

Table S4.4. Exploration of conceptual elements, learning and expertise: ***EBP Cycle Individual Steps – Step 2: Acquire***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• Acquire *Step 2 of the EBP cycle: "Acquire"* Information literacy *Being able to search and identify best, relevant evidence for a particular question.*	**An Integrated TC with WTP key to the integration** **Expert Level when fully proficient and can transfer across disciplines etc (as a librarian can) i.e. a way of thinking and practising (WTP) that incorporates many TC, concepts and FIs with key skills.** *Multiple TC which are linked and used together as a tool/in practice for EBP or research.* • A complex domain that **integrates** many simple and complex, multiple troublesome concepts some appear **transformative** to majority of students. • There is a strong argument that this is a **WTP** and **integrated overarching approach but bounded** – as slightly different for every discipline.	• Struggling first years were all concerned with their difficulties in information literacy and appraisal (Steps 1 & 2). Found these very troublesome, often into later years (e.g. 4th years still struggling), especially language of this area. • Mature students looking back to pre-transformative learning, related **transformative** *integrative application* of information skills to understanding to a patient case/problem was key in the liminal process. • ILP/Hons year was seen as essential in this **transformation,** especially writing their formal literature review.	**Info Literacy Literature:** Major area of TCF research since 2012. Tucker: Yes – agreement with troublesome areas but some differences in terms of expertise level her research was on postgraduate participants, not undergraduate student level. Some cross-disciplinary TC. Blackmore (2010) and librarian literature pre-2014: mostly agreement re troublesome nature, especially in the language and that these are integrative for full practical competency. Several conceptual areas seen to be transformative -especially information searching and evidence evaluation. Accepted that there are different levels of expertise and also many different disciplinary WTP. **Core EBP competencies:** Core competency 2. Acquire. Considered as the whole EBP step. Competencies listed here are very comprehensive and cover many concepts and skills identified by the students.	**TCF:** Yes - but several integrated concepts, major and minor – most troublesome or complex, troublesome language a key issue here, some integrative, some All seem irreversible once you 'get it'. **ITCK:** Good that all participants found this had TC characteristics. **K-S-M:** Breadth and depth of the KSM model covered – definitely Knowledge, strategies and models utilised in this learning and practice, **Tucker model:** Final model of the thesis brings together 3 key threshold concepts into one using another (a TC called "concept fusion"). **D&D Expertise:** Tucker reckoned that all levels can be represented in this, but the expert would be able to use the whole model automatically mostly (Tucker, Weedman, Bruce, & Edwards, 2014, p. 159). **Blooms:** A complex topic. Appears to include all levels of knowledge dimension and metacognitive when reached expertise in this domain. **Q&T:** Info skills seen as integrated TC complex but not included explicitly within the EBP model. Note: In contrast to Tucker, I consider that the final Tucker model should be the fusion of information structures and information vocabularies to create the information environment *as a holistic (integrated TC) practice,* rather than the final result being "concept fusion" as a TC.

Table S4.5 Exploration of conceptual elements, learning and expertise: ***EBP Cycle Individual Steps – Step 3: Critical Appraisal***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• Appraise* *Essentially this is Step 3 of the EBP cycle: "Appraise"* *Called critical appraisal in my curriculum* *Being able to critically evaluate evidence regarding internal validity (study design methods, biases, statistical analysis and interpretation and application) and external validity (generalisation or clinical significance).*	Over-arching threshold practice A complex network of troublesome concepts and skills that becomes a way of thinking and practising. • Troublesome but transformative and irreversible. • Requires understanding, integration and application of multiple concepts e.g. study design, bias etc. • WTP is key to pulling this together. • Seen as a core element of 'EBP as practice' and the EBP clinical 'way of thinking and practising'. • Essential element of overarching research threshold as well (see below).	• Definitely troublesome (all student cases noted this), the language can be troublesome also. • Transformative: more students and experts looking back can see the change point and even know when started understanding the need for close reading and critical viewing of publications etc. • Irreversible transformation to a WTP – This is particularly profound ontological change - once start being able to put this into practice, can see and feel the benefits as confidence and understanding of other related concepts grow. • The point of transformation to WTP was remembered: ILP/Hons year (research year) was instrumental for the 5th year student in understanding the importance of bias. This is backed up by formal feedback and assessment data from the medicine program.	Literature: Martindale: "Liminal talk" around this and realisation that there is flawed research and therefore this is useful. Transformation step in understanding research and EBP. Johnston and Fineout-Overhold cite this as the "most difficult step" of EBP to master for healthcare professionals (2006, p. 44).This is a commonly expressed in the healthcare literature. Core EBP competencies: Appraise and Interpret step 3.0, core competency around K and P elements – involves many critical thinking skills. Tucker: Key finding was student surprise that published research can be badly done. This in itself was the transformation point to understanding WHY to bother using EBP.	TCF: Troublesome across many types, integrative when practice this well – brings together a very complex web of concepts and skills. Transformative and irreversible – becomes a way of thinking that is seldom lost. ITCK: All participants agreed. Literature concurs also. K-S-M: Could be a massive TC = combined concepts that together are transformative. Tucker model: Not really touch on except in relation to evaluation of search hits. D&D: Experts have a totally different ability and perspective to the novice, and even compared to competent learner. Suggests transformative step necessary to view the evidence differently. Blooms: Includes all levels of the taxonomy, with emphasis on higher order thinking – e.g. evaluation and synthesis. Q&T: A definite threshold concept for students – key element of the "Validity" lens which includes critical appraisal, bias, study design, statistical analysis, interpretation and application.

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• **Understanding bias and study design*** *An important concept/skill in the critical appraisal of evidence* *Key element of Step 3 of EBP cycle.* *These are elements of the examination into internal and external validity.*	**A complex, integrated threshold concept that links to others** • A major **threshold concept** necessary for understanding validity of trials etc. • **Understanding** of many biases required for full transformation and to carry out a full critical appraisal. • Individual biases are many **troublesome-complex concepts**, maybe even TC (not this is not considered in detail here). • Understanding study design is **inextricably linked** to understanding bias and together need to critically appraise these to evaluate a study's validity.	• Seen across the all participants and within all data types as **transformative, integrative, irreversible**. • **Troublesome knowledge** in each individual bias. Recognised as alien, difficult and counterintuitive. Understanding the many types and levels of bias was acknowledged as tricky by most students and in all expert interviews. Confounding was identified as a particularly 'confounding' bias. • **Troublesome language** also involved in many of the biases and in terms such as 'validity'. • **Transformative:** as students practised appraisal of studies, they came across more and more examples and learned more, but also began to see patterns of poor research and how the bias affected the study outcomes. Finally, more mature students said they realised studies were all flawed in some way or other.	**Literature:** Less clear on this conceptual topic area. It seems a particularly confusing area of study. Some individual bias concepts identified as troublesome and transformative – e.g. bias & precision and confounding (Wills, 2017). **Core EBP competencies:** Referred to across core competency 3.0. Examining bias and confounding in a study is identified as a key element of critical appraisal, specifically: "the critical evaluation of the integrity, reliability, and applicability of health-related research which requires an understanding of the different categories of bias (such as confounding, measurement and detection bias, and reporting and publication bias), and the impact of these biases and uncertainty (random error) on estimates from studies." (Core competency 3.1)	**TCF:** Ticks all 5 of the classic characteristics but appears to follow the network model as many concepts are integrated. For whole perspective a concept fusion might be necessary (as per Tucker model). When realise that studies are biased, this helps students on their way to recognising the holistic nature of the EBP cycle model and how research is not (ever) perfect. **ITCK:** All participants recognised this one as troublesome and the more mature students found that it had been transformative for them. **K-S-M:** Threshold concept not fundamental idea – due to the transformative nature **Tucker model:** *see above.* **D&D:** In my data, taking part in proper research was important for final understanding of the importance of bias in appraisal; being able to detect the individual biases. Made sense of the knowledge of biases previously learned but not fully understood. Continued to learn into clinical years – e.g. journal club was very useful for developing learning further. Suggests that learning this is very similar (and part of) critical appraisal – takes time and practice to get it fully; e.g. exposure to authentic tasks and seeing modelled practice by clinicians. May take many years to go from competent learner to more expert level though with specialisation areas being important here, as in Tucker's findings. **Blooms:** Factual, conceptual, procedural and metacognitive knowledge required at times for this to be understood and applied. **Q&T:** Identified as a TC, part of the validity lens.

Table S4.6. Exploration of conceptual elements, learning and expertise: ***EBP Cycle Individual Steps – Step 4: Apply***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• Apply* *Clinical application Step 4 of EBP. Called the Applicability lens in my original model.* *Being able to apply the evidence to the patient's problem and situation and the environment using own knowledge and skills.*	Over-arching TC Practice **An integrated applied complex of other concepts, including TC such as clinical significance (external validity), clinical reasoning** • Involves **understanding** external validity and the difference between internal vs external validity and key threshold concepts such as clinical significance. • Also need to **recognise** own critical thinking skills and how to bring these to work together into the decision-making process, alongside clinical significance. • On the way to **over-arching clinical practice domain**. Starting to be a WTP.	• More mature students were **challenged** by the more advanced and complex issues of clinical application of evidence and the skills required to 'think like a doctor'. • Novice students less likely to talk of this – seem overwhelmed by clinical environment and at very basic level of practice and **can't see the threshold**. • Experts consider this an **over-arching threshold concept**.	Literature: Martindale: Good review of literature around the apply step of EBP in nursing and other healthcare studies. The few studies done do focus on the appraisal of evidence, rather than its application. She concludes that there needs to be more research. Medical literature: similarly, there is a paucity of good evidence in this area. Core EBP competencies: 4.0 Main core competency: "Apply" This covers decision-making process and shared decision-making of patient-doctor, but also the ability to explain to patient about their risk to help in communicating the balance of the benefit/harm in the decision-making process. Also includes understanding recommendations that come from guidelines etc.	TCF: Transformative, troublesome and irreversible. ITCK: Experts had better view of this than students – easier to perceive this as they can see the whole clinical practice picture. K-S-M: Integrated TC as includes knowledge of multiple concept sources with strategies of how to use them and models for D&D: "Thinking like a doctor" becomes "acting like a doctor" then "being a doctor" as expertise level increases. Tucker model: Not examined directly but participants considered application of new knowledge derived from the information search as being tricky. Possibly there is concept fusion happening here in some way as takes multiple TC and other concepts and practice to gain this perspective and perform this as an expert. Blooms: Highest level of operation, procedural practice and metacognition required. Q&T: Clinical Significance is the third threshold over-arching lens: amalgamates best evidence, patient values, clinical situation and the clinical evidence (includes understanding of clinical significance).

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• **Clinical significance*, clinical reasoning, judgement, clinical perspective** *Required in applying evidence back to patient – e.g. as in EBP Step 4: Applicability (above).* *All are part of (and maybe the elements required for) clinical decision-making, which is the main practice element of Applicability.*	**Could be TCs in their own right, integrated for practice** • Essential part of the clinical *practice.* • Element of the EBP Clinical Perspective (above). • Recognised as the clinical critical thinking skills. • Contains TC knowledge but there is transformation in the practice of these TC. • All these elements contain some degree of critical thinking/ perspective/ approach.	• More mature students recognised these as key. **element** of practice • Students still finding these concepts **troublesome** in later years. However, seeing patients and observing modelled practice by clinical tutors was most helpful. • Experts reckoned these were **transformative** and **essential** elements of the doctor's clinical practice.	**Literature:** Clinical reasoning/judgement have been identified as difficult to learn and essential for practice. Clinical significance as a "troublesome theme" in reading of EEG but not a TC (Moeller & Fawns, 2018, p. 393). Recognised as a core aim of clinical learning (Kinchin, Cabot, & Hay, 2010, p. 391), (Fry 2011, pp23-24). Moulton and Epstein (2011, p172-3) term these "effortful modes of cognition" for clinical practice. Wifstad (2008) considers the internal evidence for clinical judgements as difficult to integrate into EBP practice. **Core EBP competencies:** Competency 4.2: Recognises "role of clinical reasoning" as a strategy in clinical decision-making.	**TCF:** Transformation gained through practice, definitely troublesome to most students, partly due to transference of knowledge into practice. Irreversibility seen in competency of practice. **ITCK:** Experts better able to identify these as TC. Students find these really troublesome until have practised in clinical environment. **K-S-M:** Follows K-S-M well as require the knowledge, the strategies and the mental models to perform this as practice. **D&D:** Experts and more mature students see these as TC. **Tucker model:** Not relevant here. **Blooms:** Higher level cognitive skills definitely employed here – metacognitive level if integrate these. **Q&T:** Yes, considered to be TC status and under the Applicability lens.
• **Patient risk levels, assessment and estimation** *A vital concept in patient assessment and treatment, so works together with clinical reasoning to enable clinical practice. Involves understanding binomial distribution, risk and probability, and a complex balancing of benefit and harms.*	**A network or web of several troublesome and non-troublesome concepts which are transformative when put together into practice.** • Allied closely to the EBP overarching practice TC. • This could be one of the conceptual transformations that assists development of the overall EBP WTP.	• Not identified as explicitly transformative from data from student cases but seen as **complex** and **troublesome** by experts and mature students. • Experts and highest-level student saw this as **essential** for clinical decision-making. • Experts saw this as an **essential** element in the **transformation** with **WTP** to becoming an EBP clinician.	**Literature:** Less evidence on this as TC but detailed examination of these as key competencies in medicine and nursing (see below). **Core EBP competencies:** Understanding outcome measures for explanation to patients is seen as being key topic under core competencies of steps 3 and 4, so is both an evaluative element of critical appraisal of the evidence (3), but also for explanation to patient and development of management for patient (4).	**TCF:** troublesome and difficult concepts, some of which are transformative when practised and integrating with other aligned concepts. **ITCK:** Experts view these as essential concepts for practising as /being an effective clinician. **K-S-M:** Follows K-S-M well as require the knowledge, the strategies and the mental models to perform this as practice. **Tucker model:** Maybe part of a concept fusion towards the top over-arching WTP. **Blooms:** Higher level cognitive skills definitely employed here – metacognitive level if integrate these. **Q&T:** Not identified in my original model but always has been specifically targeted within my curriculum.

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• **Diagnosis & screening principles** *Clinical application concept: using evidence on diagnostic and screening tests to inform patient care such as assessment and treatment decision-making.*	**Threshold concept elements** in the underlying principles and how to apply the evaluations to patient. **Transformative when practiced – so as part of EBP clinical practice**. • Vital concepts for patient care. • Complex principles such as: sensitivity and specificity, likelihood ratios, etc. • Troublesome, transformative and irreversible. • Linked directly with risk and patient assessment/ estimation via likelihood ratios and decision-making. Combines with these for WTP of EBP clinical practice.	• Mature student adamant that this was a TC for her: **transformative**, **irreversible**. • 1st & 2nd year students all **struggled** with the definition, principles and main concepts of this, especially around the **language** of the terms used: sensitivity, specificity, likelihood ratios, positive and negative predictive values etc. • When students gained the holistic understanding of these principles it was **transformative**. • 5th year student saw clinical exposure as key to this transformative tipping point. Suddenly she found that she could understand the principles without difficulty and become competent in using this as a framework for patient assessment.	**Literature:** Broad agreement that this is troublesome knowledge and difficult for students to understand how to put into practice. No specific evidence that this is TC or transformative was found. Not covered in Martindale as such. Seen as a core part of EBP by original EBP practitioners and so has been incorporated into most of the text books on EBP and teaching EBP as a key learning point for practice, that should be taught explicitly, e.g. has a whole chapter in the seminal text: Evidence-based Medicine: How to Practice and Teach it (Straus, Glasziou, Richardson, & Haynes, 2011, pp. 137–168). **Core EBP competencies:** This is not specifically identified in Albarqouni et al (2018) but the concept of diagnosis/screening for practice and within the "Asking" step of EBP as a key question type.	**TCF:** Troublesome, transformative and irreversible. Not necessarily bounded as appears in several disciplines/domains. **ITCK:** Experts and competent students identified the transformation process and thought this was a TC. Less experienced students saw this as extremely troublesome but couldn't see beyond this. **K-S-M:** this model works for these topics – as the knowledge is the principles, the strategies are how you are taught to apply these to the patient case and the mental models are necessary. In my teaching of this I allowed for the fact that students have historically tended to visualise their mental learning of the principles in different ways and may use several of these to gain understanding and then to apply this to patient scenarios/cases. E.g. as a table of the data, as a branching flow diagram, as a diagram of 100 patients, as a ROC curve, as the plotted data. **Tucker model:** Not so relevant here. **Blooms:** Both knowledge and cognitive processes are used here – across the framework from basic understanding to expert practice. **Q&T:** Not identified in my original model but always has been specifically targeted within my curriculum (with own tutorial activity in first year that aligns with clinical teaching of neonatal screening). In previous teaching development research, I have asked 3 non-medical colleagues to try our online learning activity on this and they all found it troublesome in terms of language and conceptually, but all said that there was a point in their learning where it all became clearer and easier to understand.

Table S4.7. Exploration of conceptual elements, learning and expertise: ***EBP Cycle Individual Steps – Step 5: Assessing***

Topic	Decision and Justification	Data Evidence/Themes	Agreement from Research	Data applied to Theoretical Frameworks
• Assessing/Evaluation *This is Step 5 of EBP.* *Evaluation of your management of the patient and your own practice/ process for EBP in this case. Planning remediation and skill improvements as necessary.* *Also relevant is clinical audit. This is a mechanism for doing this at individual level or on a larger scale.*	Definitely a TC for some but not all learners. • An element of reflective clinical practice which is an accepted WTP and/or competency for professional practitioners in many disciplines and specialties. • Not all experience this threshold at university – maybe some learn this approach/WTP earlier on if they find it easier for some reason. It could be that some students are bringing in previously learned practice and are able to transfer this to the EBP cycle more easily than others.	• Data themes didn't arise explicitly through the abductive analysis around assessing own practice of putting EBP into practice, except for more mature students who understood that this contribution to the EBP cycle was essential for further self-learning and for refining the patient care. • Evaluation/reflection was a major theme for student cases when talking about the practice of information skills and critical appraisal. • Reflective practice was a theme that was strong across the participant groups. Students in particular were keen to invoke their reflective skills in practice during the data collection activities, and also to talk about how reflection aided their learning. • More mature students mentioned their confidence increased as they gained EBP skills and practice - so that they were actively reviewing their EBP practice better and with more self-assurance.	Literature: Possibly the least exciting step of the cycle, this has not drawn much research. However, reflection and learning self-evaluation are key components of medical curricula these days. Core EBP competencies: Step 5: Evaluate. 5.1 Explicitly recognises that should mention this to students: that the ability to practice EBP rests on "overcoming individual barriers to knowledge translation" and having strategies to overcome these. 5.2 Also should mention that what they call "personal clinical audit" is important element of the clinician's usual practice – i.e. comparing own practice to standards.	TCF: Transformative and integrative for some students. Clinical experts considered this as part of the usual clinical practice. ITCK: Varied in terms of the participant responses. K-S-M: Requires knowledge and strategies. Mental models would be useful but may be self-taught as there is little done to show how to do this explicitly. The practice varies greatly due to context. D&D: Those with more practice and higher-level expertise of EBP were more able to do this and see it as important. Tucker model: Not examined directly but evaluation of quality of information research is actively encouraged in teaching of searching skills. Blooms: Highest level and probably requiring some metacognition as evaluation of appraisal etc Q&T: Not present within the model diagram but is taught within the curriculum as key final step of the EBP cycle.

Table S4.8. Exploration of conceptual elements, learning and expertise. ***Specific elements of the steps: Information Literacy***

Topic	Explanation	Evidence
EBP: Information Literacy* *Examined above as Step 2 of the EBP. Specific elements analysed here as they were particularly prominent in the student case data.*	Complex network of concepts and skills that is an i**ntegrated TC WTP domain** • For full understanding and application (as an advanced skill) – requires the understanding of most of the concepts mentioned below. • Transformative, troublesome and integrative but also a WTP for those who become experts.	Literature: • Strong evidence in past 4 years for this as an Integrated TC with WTP and skill base as key to transformation. • Tucker and others more recently have identified these concepts clearly.
• Forming a search question or PICO question *This is Step 1 of EBP Cycle but has major impact of this step, so reiterated here from above.*	TC for some students • As discussed above: this is probably a complex concept/skill that is troublesome, but not clearly transformative for all students. • Involves communication with the patient to find out their needs and then careful development of a structured question. • Question needs to be focused and succinct for searching, evaluation and application of the best quality evidence.	Data: • Identified by all students and the experts actively teaching clinical or EBP. • Some but not all students (mostly first years) identified Boolean terms as problematic (including those in the focus group). • All first years mentioned struggling with PICO and some higher-level students were still struggling or realised that they were skipping this resulting in problems with their search. • Evaluation skills were universally difficult for students and were still problematic in the later, more clinical years. • Having certain skills prior to encountering the concepts clearly assisted students' ease of conceptual learning and getting this into a practice-level of competency.
• Basic database search *Which search terms to choose and how to structure the search strategy for the database?*	Integrative TC • Troublesome conceptually and transformative when expertise level increases. • Students cases struggled with this even into 5th year of study. • Competency gave confidence and increased the practice ability.	
• Choosing Boolean terms in a search ***Using Boolean logic to formulate a good search strategy.***	TC for some • Element of the above integrative TC. Appears to be a simple concept. • But, counterintuitive and confusing concept for some but not all students. • Based on Boolean logic and seems very straightforward, but involves liminality (Tucker, 2014) and is irreversible once properly understood.	
• Evaluation of sources and search hits *Key elements are finding out which database to use for search and evaluating the search hits.*	Multiple complex concepts with skills • These are probably separate complex concepts and TC but require very similar skills. • Similar but different skills required for the critical appraisal skill.	

Table S4.9. Exploration of conceptual elements, learning and expertise: ***Specific elements of the steps: Medical Biostatistics***

Topic	Explanation	Evidence
Biostatistics: Sampling Perspective	**Overarching threshold as WTP**- transformative, fully integrative.	**Literature:** • Sampling is universally accepted as a **transformative** and **troublesome** concept. • Most research agrees that it requires understanding of all of these concepts/principles for full understanding of sampling. **Data:** • Experts were unanimous in choosing this as a **major/overarching** threshold concept that was essential for full understanding of the rest of statistics. • From the data: most students who spoke about this found sampling a threshold concept and gained better understanding of it through **practical application** of handling the data**.**
• Data and distributions*	**Central concept** in statistics and research. TC characteristics but probably more 'everyday' knowledge which is reworked.	
• Central limit Theorem*	**Central** to the process of inferential statistics based on samples. Overwhelmingly seen as a particularly dense **threshold concept**.	
• Summary statistics *	Includes central tendencies, deviation measurement. **Understanding of several conceptual elements and skills required**. Not really transformational in own right, but **troublesome** for some students.	
• Degrees of Freedom	A PhD level concept but is a basic statistical principle. **A classic TC**.	
Biostatistics: Understanding Significance Perspective	**Overarching threshold concept** - **transformative, fully integrative**. **WTP** really helpful in allowing students to view this as a whole.	**Literature:** More research available 2016-2019. • Growing support that there are several TC in the understanding of statistical significance that all need to be understood and integrated to be fully actionable in practice and as a **WTP**. • **Troublesome language** recognised in statistical literature, e.g. (Kaplan, Fisher, & Rogness, 2009). • Recent study by Tam et al (2018) specifically found a worrying **misunderstanding** of p values by general practitioners. • Confidence intervals, p values and hypothesis testing all identified as **transformative** and **troublesome** by postgraduate non-stats learners and their teachers by Wills (Wills, 2017). Though they weren't perceived as troublesome as sampling but were found to be more transformative in their learning impact. **Data:** • General agreement regarding the following as **threshold concepts** by all participants: statistical significance and p values, confidence intervals and the clinical significance. • Significance is certainly a **transformative** and **troublesome** concept and requires understanding of all of the concepts for full understanding. • Experts were readier to identify effect size as a problem topic, although medical students were confused about risk as an effect size.
• Hypothesis Testing*	Central to the use of sampling in statistical testing. **Troublesome** conceptually and in language, **integrative**. **A TC.**	
• Significance*	Involves understanding sampling and the interpretation of p values, which appears to muddle everyone initially. **Troublesome, transformative and irreversible. A TC** for some students**.**	
• Confidence intervals*	As part of the expression of statistical significance but complex in its own right. Could be viewed as **a TC** for some students.	
• Type 1 and 2 errors	Basic principles underlying application of hypothesis testing and significance. Definitely a **troublesome** concept and **difficult language**.	
• Clinical significance*	Step 4 of EBP: effect size and statistical significance applied in practice alongside clinician and patient factors. **A major TC in its own right**. The difference between statistical and clinical significance is key to student understanding. Aligns with internal and external validity.	
• Effect size*	The results of hypothesis testing. Confusing and often forgotten in favour of the significance measure but **key complex concept** in clinical significance. **Direct conceptual link** to EBP risk level/assessment.	

Table S4.10 Exploration of conceptual elements, learning and expertise: ***The Research Perspective***

Topic	Explanation	Evidence
Research Perspective	**Overarching threshold practice: Transformational, fully integrative with WTP** A **key transformational step** to practitioner and expertise is actually practising research – from research question, to designing, collecting handling analysing and interpreting data. Having the understanding of all the threshold and troublesome concepts below, with the ability to judge validity would create an integrative, transformed way of seeing the work of research. **WTP** required to draw all this together cohesively.	**Literature:** Many TCF and other research supports this theoretical casing, see: (Kiley & Wisker, 2009; Martindale, 2015; Tucker, 2012). Martindale's work in particular examined research in nursing and showed that perception was very important. **Data:** Synthesis of the interview evidence suggests that this is an overarching threshold concept, which becomes a WTP once these are all integrated and put into practice.
• Research: qualitative vs quantitative method	Understanding the separate approaches and the difference between them.	**Literature:** Martindale (2015) found that nurses thought qualitative research easier to understand and more valuable than quantitative. Interestingly, in medicine the converse view prevails. **Data:** Experts 2 & 3 and 4 & 5 identified this as a problem (possibly a threshold concept) particularly in medicine.
• Data and sampling*	See 'Sampling' overarching concept above – similar/overlaps.	• General agreement regarding sampling as an **overarching transformative threshold concept**. • Students **stumble** over the difference between internal and external validity. • Experts & students all identified bias as **complex** and **troubling**, especially confounding. • In first few years students are mostly reading and evaluating research – for learning EBP and submitting assignments and projects. Learning elements with **real data, doing 'real' research'** aids **transformation** to seeing the whole perspective. • They experience actually *doing* research as 2nd years doing a simulated group research project, but major learning experience comes in 4th year with the Independent Learning Project/Honours year. The impression from evaluation of the students finishing this year is that they learn how to practice research as a whole at this point in the program and probably not before.
• Study designs*	A complex, integrated threshold concept that links to others. How research is carried out in trials and experiments. Quality of the evidence depends upon this.	
• Understanding bias*	**Troublesome** concepts making up a way of thinking about research study design, especially 'confounding', but also 'loss to follow up' and 'intention to treat'. Overlaps/equates to bias concept in EBP (see above) which this research considers a complex, integrated threshold concept that links to other concepts for EBP clinical practice WTP.	
• Validity, internal*	Students find this concept troublesome. Involves examining biases, study design, data, sampling and statistical analysis and interpretation. Complex concepts at the least. Appears to draw these all together with a research perspective.	
• Validity, external: generalisability*	Students find this concept troublesome. Overlaps with EBP-Clinical Practice overarching concept and several concepts within it e.g. clinical significance. As with internal validity, this concept draws together several others in practice.	

Table S4.11 Exploration of conceptual elements, learning and expertise. ***Other disciplinary conceptual evidence in the data***

Topic	Explanation	Evidence
Probability* *Fundamental mathematical concept used within statistical practice. Important tacit knowledge expected to use in key conceptual learning required for understanding statistical testing, significance and patient risk.*	Overarching Threshold Concept (with a disciplinary WTP overlay) • Often learned by medical students in higher level mathematics in final years of high school. Troublesome – alien and counterintuitive at times. • Knowledge or basic practice doesn't appear to be the problem but recognising when/how to use probability within statistics and patient risk/decision-making. • Not just a fundamental idea, as this has transformative element – students do start seeing the world a different way when they understand how and why probability is fundamental to statistics.	Literature: • Supports this as integrated TC/ WTP. Data: • All experts identified this or touched on it as essential, but it was rarely identified specifically by students, except to express their confusion by it or the opposite – how it helped to clarify statistical thinking for them.
Medical Science concepts *e.g. early in the first year this was Introductory material for Physiology, Biochemistry, Anatomy, Pathology, Pharmacology etc.*	Varied: TC and complex troublesome concepts mostly. • Various medical science concepts were causing learning problems students up in their current learning: troublesome, but also transformative and integrative. • Mostly these concepts are bounded within disciplines, but students recognised that there are cross-over points, overlaps, parallels and synergies across them. • Physiology (especially renal), biochemistry and anatomy were common sticking points for students in the first 3 years.	Literature: • Not examined in depth, but major concepts have been identified in many science disciplines. Less research around medical sciences until recently. Data: • Student cases and focus group students discussed these difficult concepts readily.
Transferring Medical Science knowledge into clinical perspective/practice *This is part of the EBP clinical practice perspective.*	Application/transference conceptual troublesomeness • The ready application of medical science knowledge learned mostly in the classroom to clinical scenarios and situations was acknowledged as a difficult transition point. Example: 2nd year case referred to Specific Clinical practice - Interpreting an ECG • Linked to the topic above. Possibly the troublesome part in understanding ECGs is the application of the physiology/pathology to the technical reading of a visual output.	Literature: • Not examined in depth Data: • Experts identified this as a vital part of the journey to becoming a doctor. • Focus group identified this as possibly transformational when get to apply medical science knowledge into the clinical perspective. • 5th year case looked at this from their new clinical perspective (post-transformative).
High school concepts • Maths, Geometry, Biology, Physics • Economics • Literature, History, Politics, Philosophy • Sociology and Cultural Studies	Varied: TC and complex troublesome concepts mostly. • Several different disciplinary concepts used by students to explain their previous encounters with threshold concepts. *NB Statistics was also mentioned as a transformational conceptual learning at high school - this was included in the full data analysis where appropriate.*	Literature: Not examined in depth Data: • All student cases referred to these at some point in their interviews/journals. • Experts mentioned previous school knowledge as important to current learning; tacit knowledge - link here to Vygotskian spontaneous concept.

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