Towards an Industry-Aligned Assessment of Critical Thinking in the Pharmaceutical Sciences and Beyond.

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Abstract

Research into teaching and assessing critical thinking (CT), while extensive and ongoing, has been limited by a multiplicity of definitions and frameworks. At the same time, CT is increasingly becoming a core competency for students of the STEMM (science, technology, engineering, mathematics, and medicine) disciplines to master. Some university-level courses are now explicitly aiming to develop CT skills in their students. Meanwhile, industry bodies, accreditation boards, and companies are requiring graduates to demonstrate these skills in the workplace. Prior research has indicated the value in teaching and assessing CT in the context in which graduates are expected to demonstrate it. That is to say that at university students need to do more than learn about CT abstractly and instead need to be able to practice applying CT in work-appropriate situations.

To date there is limited research around how CT is used within the industries that hire graduates from the Bachelor of Pharmaceutical Sciences. The studies discussed herein aim to better understand how relevant industries conceptualise CT in their context, and how this industry-aligned form of CT can be assessed within the university system.

The main finding of the research within this dissertation indicates that industries in our context take a more pragmatic approach to CT than prior understandings of CT. This allows us to arrive at a new *industry-aligned understanding of CT*. A review of currently-available CT assessments highlighted that no current assessment evaluates this industry-aligned CT. These CT assessments are also limited in that they do not align with the workplace context expected of our graduates. With no appropriate assessment available, the final section of this dissertation outlines the drafting and validating of a novel CT assessment, the *Monash businessThink* (MbT), which is tailored to the relevant skills and learnings of our graduates. Studies suggest that the final version of the MbT exhibits good *face validity*, *test-retest validity*, and *divergent validity*. However, several questions were flagged for review due to insufficient *internal reliability* and *sensitivity* of the MbT.

While the MbT is not useable as an assessment in its current final form, the findings of the dissertation around industry-aligned CT and novel approaches to drafting questions still hold. The MbT in its current form may be used as a workshop teaching aid to develop CT in undergraduate students of the Bachelor of Pharmaceutical Sciences and other STEMM areas.

Declaration

I hereby declare that this dissertation contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this dissertation contains no material previously published or written by another person, except where due reference is made in the text of the dissertation.

This dissertation includes two original papers published in peer reviewed journals and one submitted publication. The core theme of the dissertation is the assessment of critical thinking skills in pharmaceutical science undergraduate students. The ideas, development and writing up of all the papers in the dissertation were the principal responsibility of myself, the student, working within the Faculty of Pharmacy and Pharmaceutical Science under the supervision of Ian Larson, Gerard Rayner, and Laurence Orlando. The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

In the case of chapters 2–4, my contribution to the work involved the following:

Dissertation Chapter	Publication Title	Status	Nature and % of student contribution	Co-author name(s) Nature and % of Co-author's contribution	Co-author(s), Monash student
2	'What brings you here?' Intentions and realities of motivations to attend university.	Submitted	90%. Concept, data collection / analysis, manuscript drafting	Ian Larson, Gerard Rayner, Laurence Orlando; Input into manuscript 10%	No
3	Thinking about critical thinking: Industry perspectives.	Published	85%. Concept, data collection / analysis, manuscript drafting	Ian Larson, Gerard Rayner; Input into manuscript 10% Laurence Orlando; Concept, input into manuscript 15%	No
4	Let's talk business: The language recruiters use to attract STEMM graduates.	Published	90%. Concept, data collection / analysis, manuscript drafting	Ian Larson, Gerard Rayner, Laurence Orlando; Input into manuscript 10%	No

I have renumbered sections of submitted or published papers in order to generate a consistent and coherent presentation within the dissertation.

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Student signature: **Date:** 10 September 2019

I hereby certify that the above declaration correctly reflects the nature and extent of the student's and co-authors' contributions to this work. In instances where I am not the responsible author, I have consulted with the responsible author to agree on the respective contributions of the authors.

Main Supervisor name: Ian Larson

Main Supervisor signature: **Date:** 10 September 2019

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- Alastair Pearl

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Introduction

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1.1 Critical thinking as a tool for the modern age

In recent decades the development of critical thinking (CT) skills has become an increasing focus of undergraduate university courses. Universities in Australia and globally have listed CT as a core graduate competency or graduate outcome alongside other so-called ‘soft skills’, such as teamwork, communication and digital literacy. Australian institutions frame these variously as ‘graduate attributes’ (Bond University, 2018; The University of Adelaide, 2018), ‘graduate learning outcomes’ (Deakin University, 2018), or ‘graduate study skills’ (The University of Melbourne, 2018). Specifically, within the STEMM (science, technology, engineering, mathematics, and medicine) disciplines, the development of CT skills in undergraduates has become an explicit intended outcome of many of these courses (Flores, Matkin, Burbach, Quinn, & Harding, 2013; Maxwell, Scott, Macfarlane, & Williamson, 2010; Oliver *et al.*, 2010; Prinsley & Baranyai, 2015). Globally, this push for teaching CT skills is very much in-line with the desires of employers from the science, technology and engineering fields, with strong CT skills seen as highly important to post-education employment (Hernández-March, Martín del Peso, & Leguey, 2009; Nicolescu & Pun, 2009).

Strong CT skills and academic performance have a mutually reinforcing effect, potentially leading to increased employment outcomes and improved social outcomes. In the 19th century, reflections on the purpose of universities saw the pursuit and development of knowledge as an end in its own right (Deboick, 2010; Newman, 1854). Yet, recent studies have reported that students (Canadian University Survey Consortium, 2017), and some industries (Norton & Cherastidtham, 2016) view a university education as a means to secure more rewarding and highly-paid employment. In the Australian context a 2015 Deloitte Access Economics of Australian industry survey found that 92% of surveyed professional, scientific, and technical services desire CT in their STEMM-qualified employees (Prinsley & Baranyai, 2015).

Previous research has also shown a correlation between a formal education and development of critical reasoning skills (Ding, 2017), often through participation in experiential programs (Hannon, McBride, & Burns, 2004). Development of such reasoning skills feeds back into content learning, improving academic outcomes (Kuhn, Black, Keselman, & Kaplan, 2000; Lawson, 2004). Moreover, CT is considered as fundamentally important for fully engaged citizens in a modern world (Halpern, 2014; ten Dam & Volman, 2004). Ten Dam and Volman argue in favour of a 'social constructivist' approach in defining CT through having a greater quality of participation in society. They consider CT in the context of "[participating] critically in the communities and social practices to which a person belongs."

1.2 Defining critical thinking

A key difficulty in studying CT is the lack of clear definition. Due to the complexity of defining and measuring CT, many approaches and frameworks exist (Bailin *et al.*, 1999; Davies, 2015). When trying to teach CT, the situation becomes more complex when abstract definitions of CT need to be converted into concrete concepts (Weissberg, 2013). Thought-leaders and philosophers have debated the concept of CT over many centuries. Some commonalities do exist. CT is seen as a higher level of thinking; more than just thought (Ennis, 2015). Among modern conceptions, CT has been considered as a 'purposeful act' (Halpern, 1998) of 'reasonable and reflective thinking' (Ennis, 1993) in the form of a series of actions that a critical thinker undertakes. Facione (1990) outlines one such approach in the publication *The Delphi Report*. By way of consensus, he brings together multiple academic perspectives to define CT as a set of actions that a critical thinker undertakes. In this way he provides a procedure or method by which one can think critically. He further expands this idea by also considering one's disposition towards using CT skills. That is to say that it is not sufficient that one knows how to think critically, but also that they are inclined to critically think when appropriate. Others have also highlighted this dispositional approach (for example see Harley (2001) "lifelong values-based approach").

For some theorists, CT is less procedural in nature (Bailin, 2002). In terms of Facione's model, a person can potentially undertake the CT actions and be disposed to use the actions appropriately, but still not be a good critical thinker. For example, a student may *evaluate* (action) the results of an experiment and approach the interpretation *systematically* (disposition) but still arrive at an incorrect conclusion. Just as one can be systematic in collecting and tallying their tax deduction receipts, if you are not *accurate* in your process then your conclusion is incorrect. Under Facione's model, the student (or your tax agent) has exhibited a CT action (*to evaluate*) and undertook that action with the appropriate disposition (*systematically*) but arrived at an erroneous conclusion. The student evaluated the data but did not evaluate it well. What the student needed was a criterion or standard to which that action should be undertaken. This is the approach taken by Paul and Elder (2008) where CT is understood as intellectual standards or criteria (such as *accuracy*, *clarity*, and *relevance*) which are applied to the elements of reasoning (such as *inferences*, *concepts*, and *assumptions*) to develop intellectual traits (such as *fair-mindedness*, and *confidence in reasoning*). Nevertheless, this variety in CT understandings is then further complicated when CT is tailored to specific situations.

1.3 Critical thinking as an employability skill

Arum and Roska (2010) argue for institutional reform of colleges and universities so that graduates are able to better meet the needs of employers. In their view, and the view of the institutions in their book, critical, analytical, and logical thinking should be primary outcomes of tertiary education. Their views are echoed by the business community in calling for greater CT skills (amongst others) in modern graduates in the USA (American Management Association, 2010; Casner-Lotto & Barrington, 2006), the UK (Lowden *et al*., 2011), and Australia (Prinsley & Baranyai, 2015). Universities have responded by developing and researching ways to improve the CT skills of their students. These include problem-based learning tasks (Gholami *et al*., 2016; Kamin *et al*., 2001), workplace learning (Trede & McEwen, 2015), and Socratic questioning techniques (Golding, 2011). What these techniques have in common is an approach termed the '*infusion method*'. This method is characterised by matching explicit instruction about CT with 'real-world' scenarios in which students practice CT (Davies, 2007). Research has shown this to be a productive approach (Abrami *et al*., 2008; Angeli & Valanides, 2009; Bensley & Spero, 2014). Other research has highlighted the deficiency of CT skills proficiency in college and university students and the need for more research into barriers to the inculcation of CT as a means to improve graduate employability (Goldsmith, 2013; Good, *et al*., 2011). There is a large corpus of research around employability skills with much recent research in Australia highlighting the importance of CT amongst these skills (Oliver *et al*., 2011; Rigby *et al*., 2009). Accordingly, as we will see, many disciplines have considered CT (or an allied concept) as a key employability indicator.

Taking engineering as an example, van der Wal, Bakker, and Drijvers (2017) look into the 'techno-mathematical literacies' required of modern engineers. While not explicitly articulating 'critical thinking', they do discuss 'data literacy' and a 'sense of error' as key skills. Most tellingly, they describe these literacies as abilities to "analyse", "interpret", "draw conclusions", and "check and verify". This conceptualisation is prominent in the language used by Facione (1990, 2018), and by Paul and Elder (2008, 2012). Ahern *et al*. (2012) have gone further and attempted to find an engineering-specific definition of CT. They arrive at understanding CT as one's thinking "moving from the abstract to the concrete and back again" (Ahern *et al*., 2012, p. 131). This definition unfortunately does not shed more light on the nature of CT, but rather it considers the process of CT.

Research around CT is not limited to the STEMM disciplines with recent examples from accounting (Sin, Jones, & Wang, 2015) and business practice (Alfaro-Gramajo *et al*., 2013; Coleman, Mason, & Steagall, 2012). However, a large body of research has been conducted on CT in the sciences, and in particular nursing and health sciences. Within the sciences, research has looked into understanding CT generally in these contexts (Byrne & Johnstone, 2006; Stedman & Adams, 2012; Vieira, Tenreiro-Vieira, & Martins, 2011; Zeidler, Lederman, & Taylor, 1992) and at the discipline-level (Quitadamo *et al*., 2008; Quitadamo & Kurtz, 2007; Rudd, Baker, & Hoover, 2000; Tiruneh *et al*., 2016; Wass, Harland, & Mercer, 2011). The nursing and health sciences place emphasis on CT skills, often in the form of 'clinical reasoning' (Drennan, 2010). In medical situations, CT can be a crucial determinant of the health outcomes of the patient under the practitioner's care. Nursing education has looked into experiential learning and simulation-based learning as ways to improve their students' CT skills (Coker, 2010; Fero *et al*., 2010). Both these techniques aim to replicate situations that a graduate would face when working in a clinic or a ward. Experiential learning is 'hands-on', like an external clinical placement, whereas simulation-based learning seeks to replicate such experiences in a classroom setting. Both approaches have been found to improve graduates' clinical and critical reasoning (analogous to CT) (Coker, 2010; Fero *et al*., 2010).

1.3.1 Critical thinking in pharmacy and pharmaceutical sciences employment

Within Australia, the UK and the US, CT is enshrined as a standard in the training of new pharmacists. The Pharmaceutical Society of Australia discusses 'critical evaluation' skills as a means to review the quality and efficacy of information (Pharmaceutical Society of Australia, 2010). The General Pharmaceutical Council in the UK uses a broader approach to what they term 'critical appraisal' skills around evaluation of literature but also analysing evidence (in a clinical setting) and learning from one's errors through self-reflection (General Pharmaceutical Council, 2011). The Accreditation Council for Pharmacy Education in the US directly refers to 'critical thinking' and 'critical analysis' skills in degrees leading to a doctorate in pharmacy (Accreditation Council for Pharmacy Education, 2015). While the specific language used differs among these agencies, the general theme of CT covers all three sets of standards of pharmacy education. None of these standards are prescriptive in their approach to the teaching and assessment of CT, but rather leave the teaching to the discretion of accredited institutions. Of additional interest to institutions is the possibility that CT may act as a predictor of pharmacy students' academic success and their in-clinic performance (Allen & Bond, 2001).

Looking specifically at the pharmaceutical sciences, the call for greater critical analysis skills has been ongoing for several decades. A 1997 editorial in the journal *Pharmaceutical Research* spoke of the need for graduate pharmaceutical scientists to be able to “critically evaluate” and “make sound scientific decisions” specifically in the context of the business in which they are working (Till, 1997, p. 837). The editorial also goes on to note that “coursework and research laboratory training … are not enough to adequately prepare graduates for the pharmaceutical industry.” (Till, 1997, p. 838). These terms sit as synonyms for CT as per Facione’s (1990) conceptualisation of CT discussed in Section 1.2.

1.3.2 Understanding critical thinking in the industry context

Through better understanding the skills requirements of industry, we as educators can seek to better inculcate these skills and behaviours in our students. This is an ongoing process globally that has taken a variety of approaches to gauging industry requirements, including case studies leading to experiential engineering courses (Arlett, Lamb, Dales, Willis, & Hurdle, 2010), questionnaires investigating specific soft skills in science students and employers (Gray, Emerson, & MacKay, 2005), and targeted interviews with employers in smaller courses (Pearl, Rayner, Larson, & Orlando, 2018). These approaches capture the broad skills and behaviours required in industry, but do not consider the specific wording or phrasing that graduates will encounter through the job application process. It is imperative to identify and adapt industry understanding of these skills to allow for a closer alignment of employer expectations and educator instruction (Penkauskienė, Railienė, & Cruz, 2019, p. 811). In short, this leads to a better matching of what employers say they want, and what and how we teach.

1.4 Context-dependent critical thinking

1.4.1 Context-specificity and transferability of critical thinking

Many definitions of CT skills assume that they are generalisable across multiple domains or multiple areas of life, study and work. The implication of generalisable CT skills is that CT can be taught as a set of generic rather than contextual skills (Abrami *et al.*, 2015). If it is true that CT skills can be generalised, then it stands to reason that a effective critical thinker is able to take their generalised CT skills and apply them (or transfer them) to novel yet discipline-specific situations. However, there is ongoing debate about the ability of a person to take CT competencies developed in the classroom and apply (transfer) them spontaneously in novel situations (Ennis, 1989; McPeck, 1990; Perkins & Salomon, 1989) or even the degree to which this transfer of skills is currently being done (Davies, 2016). The contrary position is that CT skills are specific to the context in which they are taught. Discussion on this topic dates back to Socrates, but more recently to the start of the 20th century in the West. Early work on education by Thorndike and Woodworth (1901) approached knowledge and skills gain as being intimately linked with the domain in which the knowledge lay. As such, transfer of skills (such as CT) between situations may be limited by the degree of similarity between situations (Bransford, Brown, & Cocking, 2000). McPeck (1990) argues against the idea of 'generic' CT, as he understands it to derive from the object of thought. He argues that due to the variability in the subjects of thought (*i.e.* there are many things that can be thought about), CT must pertain to the subject of thought rather than be generalised across all possible subjects of thought. This domain-specific view of CT appears antithetical to the ability to teach and assess CT broadly and suggests that CT needs to be taught within the context in which it will be applied. When discussing methods to teaching CT, Ennis (1989, 1990) makes concessions to McPeck's *specifist* view by arguing in favour of what he terms the 'mixed' approach to CT instruction in which a learner undertakes explicit, separate CT instruction alongside the content of a standard course. In this way, he posits, the learner is exposed to CT and is able to apply it within the context of what they are learning. The mixed approach is supported by the results of a meta-analysis by Abrami *et al*. (2015), who found that a mixed approach to CT instruction (as defined by Ennis) generated a greater gain in CT ability than through other approaches that teach CT implicitly. Similarly, Halpern (1998) describes the goal of CT instruction as being able to transfer these skills out of the classroom into "real-world" settings. Accordingly, she sees the assessment of CT then as needing to be ongoing and conducted in various scenarios that require the higher-order thinking encapsulated by CT.

There is no reason that CT cannot be understood as a set of generalisable skills that are honed or applied in specific contexts. In this way, CT is defined in a similar way to that of Davies' (2007) infusion approach to teaching CT, *i.e.* separate explicit CT instruction and context-specific practice. It is this *context-refined* approach to CT that this dissertation takes forward: a set of common CT skills that are adapted and refined in the specific context they are applied.

While the majority of studies appear to support the notion that CT skills are indeed transferable, some studies have found such transfer to be limited. In a large-scale study, Meijer (2007) found that psychology students were generally not able to transfer their CT skills between a psychology and non-psychology domain. In that study, students were tasked with responding to a question addressing the issue of whether two events had a causal or correlational relationship. The first version of this question focussed on content from within their coursework (*i.e.* within the domain of psychology). In a separate instance, students responded to a similar question this time taken from everyday life (non-psychology domain). Results indicated a statistically significant decrease in performance when moving from the psychology to non-psychology domain. There are a couple of criticisms of this study that should be noted. Firstly, the study was limited to the CT ideas of causality and correlation. While the causation/correlation dichotomy is a test of logical reasoning (which in turn is a part of CT), it is only one subset of CT (Halpern, 2014). Secondly, both forms of the questions were generally poorly answered. This begs the questions of whether the participants were strong critical thinkers initially and whether the results would become more or less clear if a greater number of participants answered either question correctly. Other researchers have also noted a lack of skills transfer (Sternberg, 1981). Without more research, it is difficult to determine the validity of the claimed transferability issue in CT instruction.

1.4.2 Approaches to addressing the transferability issue

If indeed transferability is a concern, research has indicated a range of options that may ameliorate its effect. One method is by using authentic examples that reflect a situation in which students would be required to utilise their CT skills. Bransford, Brown, and Cocking (2000) discuss such ideas by describing how students may be presented with a specific task in one specific context before being presented with another, similar context. This, they posit, enhances student ability to identify which general principles can be transferred. One way this concept may be applied is through a valid or realistic representation of the situation in which the student would be expected to use the desired skill. The use of authentic tasks, especially in assessment, is supported by the work of Lund

(1997), who describes how well-developed authentic assessments can induce higher-order thinking, within which CT falls. In her view, this type of assessment should examine both the result of the thought and the thought process itself. She argues that this allows the assessor to detect, for example, "faulty logic … [that] could mean wrong decisions in future…" (Lund, 1997, p. 27). She describes 'well-developed authentic assessments' as characterising, amongst others, the following traits; (1) meaningful tasks that simulate real-world tasks, (2) the aim to elicit higher level thinking rather than rote memorisation, (3) clearly articulated assessment criteria, (4) formative, rather than summative assessment, (5) assessment of the thought process as well as the end products. Lund argues that through this, the assessor is able to detect such faulty logic. At least one small-scale study has indicated a moderate improvement in CT skills through teaching that uses authentic tasks (Colletti, 2011). However, while this study showed improvement in CT skills by using authentic tasks, it did not measure whether these CT skills are transferable. Other research, in support of the use of authentic assessment, indicates that these assessments utilise CT skills and are effective in addressing the issue of skills transfer, while not specifically assessing CT itself (Ashford-Rowe, Herrington, & Brown, 2013; Lund, 1997; Sternberg, 1981; Tammaro & Solco, 2013). This includes use of authentic assessment of CT at a tertiary level (Buffamanti, David, & Morris, 2006), which reported mixed levels of benefit. In a pharmacy context, the introduction of problem-based learning (PBL) (Cisneros, Salisbury-Glennon, & Anderson-Harper, 2002) and self-reflection (Austin, Gregory, & Chiu, 2008) into curricula have generated positive outcomes (Hogan & Lundquist, 2006; Jacob, Dhing, & Malone, 2019). Similar findings have been reported more broadly in STEMM (Beier *et al*., 2019; Kingston, 2018; Li, Wang, Zhu, Zhu, & Sun, 2019).

Another method to address transferability of CT may be through a constructivist approach in which knowledge is constructed through interaction with phenomena (Watts, Jofili, & Bezerra, 1997). That is, students would be exposed to authentic situations separate to an assessment task. In which their CT is being developed contextually, rather than taught abstractly or purely theoretically. CT would be an ideal candidate for a constructivist approach, as it often concerns itself with "complex multi-layered circumstances which entail, for instance, awkward or unresolvable issues which cannot be tackled easily"

(Watts *et al*., 1997). The complexity of these ‘circumstances’ and ‘issues’ align with the types of CT problems envisaged by social constructivists such as ten Dam and Volman (2004), *inter alia*.

Phelan (2012) found a significant gain in self-reported transfer of CT to situations external to the classroom, and he postulated that this is most likely due to the explicit CT instruction and reflective activities that students were required to undertake. As Phelan further noted, this observation is very much in line with the views of van Gelder (2005) in that transfer of any skill requires conscious practice. Similarly, in a study by Helsdingen, van Gog, and van Merriënboer (2011), participants were assigned to either regular or random schedules for practicing “complex judgement tasks”. These schedules were supplemented with post-practice CT prompts that lead to substantial performance gains on these “complex tasks”. They found that explicit CT instruction leads to transfer when participants are prompted to practice and utilise CT competencies. This specific teaching of CT also appeared to have a beneficial effect on economics students’ reasoning skills (Heijltjes, van Gog, Leppink, & Paas, 2014). Much of the literature in this area appears to contend that CT skills and other thinking skills can indeed be transferred out of the classroom, often in part due to effective CT instruction (Harley, 2001; Randi & Corno, 2007; Thibodeau, 2003).

1.4.3 Critical thinking in the pharmaceutical sciences context

The pharmaceutical sciences are taught at the undergraduate level in Australia and are a separate area of study to pharmacy practice. A pharmaceutical sciences course is offered at the undergraduate level in Australia at a wide range of universities (Griffith University, 2017; Monash University, 2017b; RMIT University, 2017a; The University of Adelaide, 2019; The University of Western Australia, 2017; University of Canberra, 2019; University of South Australia, 2019; Victoria University, 2017). These courses comprise a combination of the chemical and physical sciences, applied to pharmacy and health sciences contexts. This is distinct from a pharmacy or pharmacy practice course that, while considering basic pharmaceutical sciences, focusses instead on human physiology, disease pathology, and professional pharmacy skills (Monash University, 2017a; RMIT University, 2017b). This distinction is important, because while studies into CT skills development have been conducted in many educational areas, including pharmacy

(Gleason *et al*., 2013; Peeters & Boddu, 2016; Persky, Medina, & Castleberry, 2019), a search of the literature has not uncovered any studies to date that look at the CT competencies of pharmaceutical sciences undergraduates. As graduates from our pharmaceutical sciences course typically go on to employment within pharmaceutical and consumer goods companies, a most direct approach to understanding how CT is conceptualised by these industries is to query them directly. We can then look for thinking approaches that together can be considered as CT by comparing against currently accepted understandings of CT. Examination of this gap in the literature is encouraged by work that found benefit for each stakeholder group in linking industry experience with the educational setting, such as benefitting industry through access to strongly developed graduates (Brunton & Coll, 2005).

1.5 Assessing critical thinking at university

Following from the discussion of transferability and authentic assessments, it is not surprising that some disciplines have developed a context-specific test of CT ability for measuring the degree to which their courses instil CT into their students. Several researchers have created bespoke CT assessments or tools in their disciplines, including biology (Bissell & Lemons, 2006), chemistry (Cloonan & Hutchinson, 2011), physics (Tiruneh *et al*., 2016), and other interdisciplinary science studies (Stein *et al*., 2007). Most of these types of assessments are non-commercial in nature. There do however exist a raft of commercially available CT assessments.

As previously discussed, nursing and the health sciences have a history of teaching and developing CT skills throughout their courses. A such, a number of recent publications have focussed on measuring CT (Carter, Creedy, & Sidebotham, 2015; Wangenstten *et al*., 2010) and developing tools to assess CT (Yuan *et al*., 2014). Previously validated CT assessments, such as the *Health Sciences Reasoning Test* (HSRT), have been used extensively to assess CT skills of undergraduates (Huhn *et al*., 2013; Hunter, Pitt, Croce, & Roche, 2014). The HSRT focuses on skills described by Facione (1990) (*i.e. interpretation*, *analysis*, *evaluation*, *inference*, *explanation*, *self-regulation*) in “clinical and professional contexts” (Insight Assessment, 2016). Interestingly the HSRT has also been trialled as a pre-admission diagnostic test for pharmacy (Kelsch & Friesner, 2014). This suggests that CT tests are increasingly becoming high-stakes assessments rather than simple diagnostic tools. Although there are similarities between pharmacy and pharmaceutical sciences courses, it is likely that this test was intended to assess the CT skills used when handling patients (pharmacy practice) rather than those used for drug discovery and formulation (pharmaceutical sciences). Thus while the HRST may be *industry-aligned* for pharmacy, it is not for the pharmaceutical sciences. Again, however, there does not appear to be a specific test for the pharmaceutical sciences and those industries that hire from the Bachelor of Pharmaceutical Science course. This indicates a potential avenue of exploration and development of such a test for the pharmaceutical sciences.

Two widely used, and researched, assessments in pharmacy and STEMM disciplines are the California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Disposition Index (CCTDI), both of which are based on the theories of Facione (1990). Studies have previously been undertaken into potential correlations between the CCTST and other academic or socioeconomic measures (Danielson, Schwartz, & Lippmann, 2015), the efficacy of translations (İskifoğlu & Ağazade, 2013; Yeh, 2002), and reviews of the CCTST and the CCTDI (Kakai, 2003; Walsh, Seldomridge, & Badros, 2007). Research on the use of the CCTST and CCTDI in pharmacy have yielded mixed results, with some finding no statistical gain (Cisneros, 2009) and others finding a mild positive gain (Miller, 2003) during pharmacy education. This previous research lacks a consideration of the efficacy of the CCTST and CCTDI as a measurement tool within pharmacy, and STEMM more broadly.

Additional to the efficacy of a test, research on test-taking behaviour has indicated a large determinant of performance lies in the test takers' motivation. One aspect that influences motivation is the degree to which the content of the test is perceived, by the test-taker, to be related to the content of their job; that is, the degree to which the test has sufficient *face validity*. In one study, Chan, Schmitt, DeShon, Clause, and Delbridge (1997) investigated the effects of the face validity of a test on test-taking motivation and found that motivation was mediated by perceived face validity. In measuring CT specifically, Liu, Mao, Frankel, and Xu (2016) found differences in test-taking motivation lead to an "alarmingly large" performance gap between highly-motivated and less-motivated respondents. Liu et al. (2016, p. 691) notes that the concern around motivational impact for low stakes testing is an area of ongoing research interest.

1.6 Designing a critical thinking assessment for university

1.6.1 Confounding factors

There are a range of studied factors that potentially obscure measured changes in CT ability including; age (Howard, Tang, & Austin, 2014), gender (Arslan, Gulveren, & Aydin, 2014), course of study (Arslan, Gulveren, & Aydin, 2014), socioeconomic and family factors (Arslan, Gulveren, & Aydin, 2014), cultural background (Manalo *et al*., 2013), test-taker's mother tongue (Floyd, 2011), university achievement (Howard, Tang, & Austin, 2014; Romeo, 2013), year-level (Arslan, Gulveren, & Aydin, 2014), and disposition towards use of CT (Clifford, Boufal, & Kurtz, 2004; Macpherson & Stanovich, 2007). A good assessment of CT needs to be able to differentiate between differences in CT skills and differences in these factors.

1.6.2 Characteristics of a valid critical thinking assessment

From a general assessment perspective, Scouller (1998) found that essay-style questions required students to engage in deeper level thinking compared to multiple-choice style questions. Similar to the findings by Liu, Frankel, and Roohr (2014), only a minority of the 47 commercially-available CT tests studied in this report utilise an open-response format (n = 11) (either standalone, or in combination with closed-response options). We thus note that an MCQ style of response may lack face validity (Liu et al., 2014). While some researchers argue in favour of open-response formats especially in authentic assessments whilst acknowledging the potential for subjectivity in scoring (for example, such as in essay-style assessments) (see Ashford-Rowe et al. (2013); Eubanks (2009); Stein and Haynes (2011)), others also argue for the pragmatism associated with closed-response formats (Downing, 2006; Ennis, 2008; Haladyna & Rodriguez, 2013). Proponents of closed-response format highlight the ease of administration to large groups as a primary consideration. Conversely, critics of this approach note the difficulty in assessing the thought process of the respondent (Norris, 1989). Other criticisms levelled at closed-response formats are the possibility of 'gaming the test', by which highly able students are able to deduce clues to the correct response and in doing so reduce the pool of options from which they must select. However, the use of well-written questions and responses has been shown to reduce this possibility (Downing, 2006; Haladyna & Rodriguez, 2013). Complaints that respondents could simply guess the correct response are statistically fallacious. For example, with a minimal increase in plausible distractors, the expected ‘score’ from guessing decreases significantly (Haladyna & Rodriguez, 2013). Ideally, any assessment of CT should be performance-based or determined by a portfolio of evidence of strong CT use (Arend, 2011; Benjamin, 2014; Bensley & Murtagh, 2011).

1.6.3 Using authentic assessment and case studies

Biggs and Tang (2011) discuss the need to align assessment with intended learning outcomes, and an aligned assessment must thus reflect the reality of undertaking CT in industry. Following the idea of authentic assessment, this then would imply the use of industry-based problems to form the assessment. In this way, authentic tasks and authentic assessments aim to replicate ‘real-world’ experiences (Bensley & Murtagh, 2011; Montgomery, 2002; Wiggins, 2011), utilising appropriate skills and knowledge (Poindexter, Hagler, & Lindell, 2015; Terwilliger, 1997). Terwilliger (1997) specifically posits that the skills being assessed should not exclude or ignore the domain of knowledge in which the assessment sits. This further reinforces the case for industry-based problems to form the basis of assessment.

The following points are noted as key characteristics of authentic tasks and authentic assessments, (Wiggins (1998), as cited in Adams (2011); Herrington, Reeves, and Oliver (2006)) similar to and in addition to those outlined by Lund (1997).

1. Realism / real-world relevance
    - Assessment is reflective of behaviours in the ‘real-world’, and should reflect the context in which the problem would normally be encountered
2. Solving unstructured problems, allowing multiple solutions
    - Problems should be ill-defined requiring respondents to undertake CT and arrive at multiple potential solutions
3. Comprising a complex activity, requiring a wide range of skills
    - Respondents should engage CT skills in tackling the problem
4. Feedback, practice and reflection
    - Assessment allows for feedback to be given, multiple practice to be undertaken and self-reflection to occur
5. Provide opportunity to investigate task from multiple perspectives
    - Does not force a respondent into using a single ‘correct’ approach to the problem

6. Provide an opportunity for collaboration
7. Foster cross-domain thinking

One means of generating an authentic assessment is to use case studies as the content basis of the assessment. Here, a case study is taken as a study investigating a "contemporary phenomenon … in its real-world context" (Yin, 2018). As presented above, a case study addresses the concerns of realism, potentially utilising unstructured or ill-defined problems, requiring of complex thought, enable practice, and reflection. Case studies then provide one viable avenue to developing the content of an authentic assessment.

Other disciplines have identified and utilised authentic assessments to develop students' workplace skills. Such examples cover a variety of fields including engineering; field notes to promote CT (Kelley, 2011); pre-service teacher assessment (Maxwell, 2012), and problem-based learning tasks in undergraduate nursing education to develop CT and clinical reasoning (Martyn, Terwijn, Kek, & Huijser, 2014; Popil, 2011). In discussing the value of case studies in nursing education, Popil (2011) notes benefits to include teaching "complex situations requiring problem solving", in particular including the teaching of CT skills. This lends credence to the idea of case studies as a valuable tool for development of undergraduates' CT skills in other STEMM fields.

1.7 Research questions

The push from industry for greater CT and related skills in STEM graduates in Australia and globally, provides an opportunity for the higher education sector to teach these skills within bachelor's degrees, tertiary certificates, diplomas and associate degrees. To determine the effectiveness of any CT teaching interventions in the Bachelor of Pharmaceutical Science there must also be a valid and reliable test. This dissertation will address several research questions in order to arrive at an appropriate assessment regime of CT skills.

1. What is the most appropriate and relevant approach to CT for the graduates of the Bachelor of Pharmaceutical Science, in terms of their intended graduate destinations?

2. What learnings from other commercially-available tests of CT can be utilised in the development of an appropriate assessment of CT?
3. How might an appropriate CT assessment be developed and validated?

Subsequent emerging research questions are also addressed within each experimental chapter.

1.8 Dissertation structure

Following this introductory first chapter, this dissertation is split into two sections; the first section investigates at how CT is conceptualised within the context of graduates working within industry, and the second section describes a novel approach to assessing this industry conceptualisation.

Chapter 1 – Introduction

An introduction to the concepts, arguments and literature around defining, teaching and assessing CT in higher education.

Section 1 Understanding Critical Thinking in the Industry Context

Chapter 2 – Student Motivations to Attend University

As CT is a broadly defined field, it is important to first know in what situations students would be expected to demonstrate CT skills. I hypothesise that students opt to attend university as a means to securing employment within the field. The findings of this first study inform the context of the following chapters.

Chapter 3 – Industry Conceptualisations of Critical Thinking

Now taking the perspective of those employers who will likely employ graduates for the Bachelor of Pharmaceutical Science degree, I want to understand how they conceptualise CT within the context of working in their companies and within their respective industries. These findings then form the basis of industry-aligned CT.

Chapter 4 – Critical Thinking in Job Advertisements

Before moving towards the assessment of CT, I want to better understand how industry communicates their understandings and expectations of CT to graduates. This study examines twelve months of relevant job advertisements and investigates their use of CT and higher-order thinking concepts when recruiting graduates.

Section 2 Assessing Critical Thinking in the University Context

Chapter 5 – Efficacy of a Commercially-Available Critical Thinking Assessment

To assess industry-aligned CT I want to first see whether any currently available tests are appropriate for use in the Bachelor of Pharmaceutical Science. This study outlines the efficacy of one of the most widely reported tests of CT skills when administered to students within the Bachelor of Pharmaceutical Science course.

Chapter 6 – Making a Novel Critical Thinking Assessment

This chapter details the approach I took to develop and refine a novel test of CT skills that aims to assess the industry-aligned understanding of CT.

Chapter 7 – Validating a Novel Critical Thinking Assessment

In this final study I report on the findings from the validation and reliability studies conducted on the novel CT assessment tool.

Chapter 8 – Synthesis

Drawing together the findings of previous chapters to address the thesis questions.

Section 1

Understanding Critical Thinking in the Industry Context

Chapter 2

Student Motivations to Attend University

Preface

This chapter details a study into the motivations that drive students to attend university, to choose their course, and to decide on their options following graduation. This chapter considers differences in students choosing to enrol in *vocationally-oriented* vs. *generalist* degrees/courses. For the purpose of this chapter, *vocationally-oriented* courses are three or four years of study at a tertiary institution where the topic of that study has a clear (and sometimes singular) vocational outcome. For example, a pharmacy degree leads one to become a pharmacist. Conversely, *generalist* courses are those that lead to a larger breadth of potential occupations, such as one might gain having completed an arts or general sciences degree. This distinction is further discussed within his chapter.

While this study looks at students from a range of courses, in this dissertation we are only interested in the responses from students of the Bachelor of Pharmaceutical Science. Their motivations to initially attend university and what they intend to do after graduation will be the most important findings from this study.

Chapter Contents

This chapter is under consideration for publication in a peer-reviewed journal.

The manuscript is reproduced in full below with minor editing of layout and formatting for consistency. Reference list and any appendices are reproduced in the dissertation end matter.

'What brings you here?' Intentions and realities of motivations to attend university.

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Abstract

To date, in Australia, there has been little research into the reasons why students choose to attend university and to select their particular course. This study surveyed 566 first-year and 58 third-year undergraduate students from three STEMM discipline areas to investigate their motivations to attend university, their motivations to choose their particular course, and their post graduation intentions. This study utilised students from the Bachelors of Science, Pharmaceutical Sciences, and Pharmacy to enable comparisons between domestic and international cohorts, generalist and vocationally-oriented degrees, and Australia-based and Malaysia-based cohorts. Our findings support the notion that vocationally-oriented degrees tend to attract more extrinsically motivated students with intention to enter the workforce immediately after graduation. Analyses of post graduation intention also indicates that intention to enter the workforce may increase as students progress through their degrees. Implications and opportunities for tertiary institutions to better engage these cohorts are also further discussed.

2.1 Introduction

There are many reasons why students undertake a university education. Such motivations include parental encouragement (Alling, 1999; Hunt *et al*., 2017; Deborah J. Kennett, Reed, & Stuart, 2013; van Herpen, Meeuwisse, Hofman, Severiens, & Arends, 2017), cultural norms (Deborah J. Kennett *et al*., 2013; van Herpen *et al*., 2017), improving one's job prospects (Hunt *et al*., 2017; Kember, Hong, & Ho, 2008; D. J. Kennett, Reed, & Lam, 2011; Reed, Kennett, & Emond, 2015; van Herpen *et al*., 2017), a sense of belonging (Kember *et al*., 2008), and interest in the area of study/enjoyment of learning (Henderson-King & Smith, 2006; Hunt *et al*., 2017; Kember *et al*., 2008; Deborah J. Kennett *et al*., 2013; Reed *et al*., 2015). An understanding of these motivations has variously been used to predict university retention in different sub-groups, such as students with a disability (Alling, 1999; Reed *et al*., 2015), or students from culturally and linguistically diverse backgrounds (de Silva, Zakzanis, Henderson, & Ravindran, 2017). Other studies have looked for correlations between student levels of motivation and their adjustment to university (Deborah J. Kennett *et al*., 2013), and the challenges facing first-in-family students (Hunt *et al*., 2017). By studying student motivations, universities can better identify students at risk of dropping out (Deborah J. Kennett *et al*., 2013; van Herpen *et al*., 2017), or best adapt courses to students experiencing difficulties or having particular disabilities (Reed *et al*., 2015). A common feature of these studies is the aggregation of students across disciplines (where disciplines are indicated), which implies that they have homogenous motivations for attending university. Further, many studies caveat their results as being potentially limited to their particular sociocultural context. Given these constraints and assumptions, we set out to gather insights into unique sociocultural contexts to allow for further comparisons.

The tendency for humans towards self-improvement and growth underlies self-determination theory in which the natural inclination is for humans to progress towards "psychological growth, internalization, and well-being" (Van den Broeck, Ferris, Chang, & Rosen, 2016). Inherent to this self-improvement are *intrinsic motivators* (engaging in an inherently interesting behaviours and activities) and *extrinsic motivators* (behaviours or activities encouraged through pressures derived externally to the individual). Ryan and Deci (2000, p. 65) distinguish between these by defining *intrinsic motivations* as those that "satisfy the innate psychological needs for competence and autonomy …" and *extrinsic motivators* as those that "are executed because they are instrumental to some separable consequence". These map closely with the approach of Deborah J. Kennett *et al*. (2013, p. 127), who defined motivations as being *internally based* (self-imposed reasons, such as 'personal growth') or *externally based* (other-imposed reasons, such as 'to please one's parents'). Both definitions align with pre-existing conceptions of motivation as a function of *expectancy* ('how likely I am to attain the goal') and *value* ('how valuable it is to attain that goal') (see Ambrose (2010), for a more thorough discussion of this approach).

2.1.1 Increasing students and changing demographics

In the Australian context, there appears to have been limited research of such motivations in undergraduate students' choices regarding tertiary study. Compared to other culturally similar countries, Australia has experienced a demographic shift in students attending university in recent years, in part driven by policy changes and global financial factors. Since the uncapping of university places in 2009, the proportion of eligible students accepting offers to attend university has increased by 18% (from 2008 to 2015) (Department of Education and Training, 2018). This increase is disproportionate to population growth over this period (11% from December 2008 to December 2015) (Australian Bureau of Statistics, 2019a) and to the shrinkage of working age Australian residents (1.8% decline in the proportion of Australians aged 15–64 years from 2009 to 2017) (Australian Bureau of Statistics, 2019a). This indicates that the increase in students attending university is independent of natural population variation.

2.1.2 The Western and Eastern student motivations in an Australian context

Parallel to the changes in low-SES (socioeconomic status) and indigenous students, there has been a marked increase in the number of overseas[1] undergraduate and graduate students studying in Australia. Australian Government Department of Education and Training (2019) data show an increase in such enrolments from 116,934 in 2002 to 350,472 in 2017[2]. However, as a proportion of all students, the number of international

[1] For the purposes of this research, the terms 'Eastern' and 'Western' are shorthand for countries with cultural influences from the East Asian region (People's Republic of China, Japan, Korea, Republic of China (Taiwan), Vietnam, Malaysia, Singapore, *etc*.) and Western Europe (Australia, Western European countries, North American countries), respectively.

[2] Note that these figures are for 'student enrolments' which combine commencing and continuing students.

students has remained approximately constant. Between 2007 and 2016, the proportion of international student enrolments increased from 26.5% (Department of Education and Training, 2007) to 26.8% of all enrolments (Department of Education and Training, 2016). However, the distribution of international students among Australian universities is not uniform. The top-tier Australian universities, the 'Group of 8' universities, have an average of 29.9% international student enrolments in 2016, compared to 22.7% for other institutions (Department of Education and Training, 2016).

Larger and higher ranked universities are good candidates for research into differences in international/domestic student motivations as these universities are seeing this increase in international student enrolments to a greater degree than other institutions (Department of Education and Training, 2016). These international students wish to engage with familiar cultural settings and so bring their sociocultural experiences into the Australian university context (Sawir, Marginson, Deumert, Nyland, & Ramia, 2007). In a similar vein, research into academic achievement differences between Eastern and Western students has indicated clear differences in the effects that intrinsic and extrinsic motivations have on academic achievement (Bempechat & Drago-Severson, 1999; Martin, Yu, & Hau, 2013; Zhu & Leung, 2010). Again, while no specific research has yet been conducted, it stands to reason that differences exist between international and domestic students' motivations for choosing to attend university, and choosing their specific course, based on differences in their lived and cultural experiences. Yet the question remains as to how different their motivations are likely to be, compared to a domestic Australian student. Part of the answer may lay in their country of origin. We note that these potential cultural differences are more dependent on country of origin rather than identified ethnic background in that Australian domestic students of Asian ethnicity have been shown to display similar motivations to their Anglo-Saxon/Anglo-Celtic peers (McInerney, 2008; Yeung, McInerney, & Ali, 2014).

In an Australian context, the largest proportion of international students come from the People's Republic of China (38% of international student enrolments, as at December 2017) (Department of Education and Training, 2019). The top five countries for international students in 2017 were, in descending order; P.R. China, India, Nepal, Vietnam, and Malaysia. These five countries account for 68% of all international student enrolments in 2017 (Department of Education and Training, 2019).

Looking broadly, literature comparing academic motivations of eastern and western students promulgate the theory of the individualistic-collectivistic divide between Western and East Asian societies (Helmke & Tuyet, 2006; Hui, Sun, Chow, & Chu, 2011; King, McInerney, & Watkins, 2012; Lee, 2014). The collectivistic East Asian societies are said to act for the benefit of the group/family/community and so are influenced more strongly by extrinsic motivators. This would lead one to think that students from these backgrounds are potentially more greatly motivated by family/social pressures to attend university and, to quote a stereotypical trope, to get a 'good' job. However, like any good trope, this perception is likely an oversimplification of reality (Helmke & Tuyet, 2006; Yeung *et al*., 2014) and deserves further investigation.

2.1.3 A clear job outcome or a generalist degree?

If, in general, students access the university system as a means to improve their employment outcomes (Hunt *et al*., 2017; Kember *et al*., 2008; Reed *et al*., 2015; van Herpen *et al*., 2017) then it stands to reason that their choice of course may be influenced by perceived career outcomes of that course. So, in investigating student reasons to choose their course it is worth considering potential differences in student motivations between vocationally-aligned courses (those with clear career outcomes) and generalist courses (broader in scope and less clear career outcomes). Top-tier Australian universities differentiate between two styles of undergraduate degrees: 'structured', 'professional', or 'specialist' in contrast to 'broad', 'flexible', or 'comprehensive'. The former descriptors align with vocationally-oriented courses mentioned previously, with the latter aligning with generalist degrees such as science or arts (Monash University, *n.d.*-a; The Australian National University, *n.d.*; The University of Melbourne, *n.d.*-b).

In terms of job outcomes, there is a distinct difference between vocationally-oriented and generalist courses. Australian Government data from 2018 show that graduates from vocationally-aligned courses are typically employed more rapidly, and initially at higher rates, than their counterparts with more generalist degrees (Social Research Centre, 2019). Specifically, the report noted that "*Pharmacy, Medicine, Rehabilitation and Dentistry undergraduates had the highest rates of full-time employment*" (Social Research

Centre, 2019, p. 3), while employment from generalist degrees typically lags. For example, in 2018, 97.2% of pharmacy graduates were employed within four months of graduation compared to 64.6% of science and mathematics graduates. The report does however note that employment from some vocationally-oriented degrees (such as pharmacy in Australia) does benefit from an industry-based graduate study year (as part of professional registration requirements) (Social Research Centre, 2019, p. 3). However, other vocationally-oriented courses do still have comparatively high short-term employment outcomes (*e.g.* engineering; 83.1% employment) compared to those of generalist degrees.

If we couple the above findings with the notion that students may opt for generalist degrees 'if they are not sure what they want to do' or want to 'keep their options open', then it would stand to reason that students entering generalist degrees may have motivations that are less job-focused than those entering vocationally-oriented degrees. However, in the Australian context, there appears to have been a lack of research in this area.

2.1.4 Generalist and vocation-oriented degrees

This study investigates the motivations and experiences of students completing the Bachelor of Pharmaceutical Sciences (BPharmSc) at Monash University, Australia compared to those in the Bachelor of Science (BSc) and Bachelor of Pharmacy (BPharm). The BPharmSc is a specialised form of the Bachelor of Science (BSc) in that it focuses on pharmacology, human physiology, and biochemistry and product formulation. The BSc at Monash University offers a much wider range of major study areas, and for the purposes of this research will be treated as the 'generalist' form of the BPharmSc. In terms of vocational outcomes, the BPharmSc streams towards the pharmaceutical industry and also prepares the students for work in industries focusing on a range of consumer goods and scientific research. In comparison, the BPharm is vocationally-oriented, with a clear pathway to industry while also sharing many of the same study areas as the BPharmSc. So, for the purposes of this research, the BPharm and BSc are treated as the vocationally-oriented and generalist forms of the BPharmSc, respectively.

2.2 Aims

This study aims to investigate the differences in intrinsic and extrinsic motivations that lead students to attend university. This study will look specifically at students entering first-year undergraduate studies of the Bachelor of Science (BSc), the Bachelor of Pharmaceutical Sciences (BPharmSc), and the Bachelor of Pharmacy (BPharm) at an Australian university.

More specifically, this study sets out to investigate;

- Potential differences in motivations to attend university,
- Potential differences in reason to choose a course, and
- Anticipated destinations after graduation.

This study will investigate the above points from three perspectives;

- vocationally-oriented courses vs. generalist courses,
- domestic students vs. international students studying in Australia, and
- students studying the same course in Australia and Malaysia.

Data from the BSc, and BPharmSc was collected from Australian-based campuses, whereas data from the BPharm was collected from Australia-based and Malaysia-based campuses. An identical BPharm is taught at both the Australian and Malaysian campuses.

2.3 Sample

This survey was offered to all first-year students entering the BSc, BPharmSc, and BPharm at Monash University, Australia. For international comparison, the survey was also offered to first-year students entering the BPharm at Monash University Malaysia campus, Kuala Lumpur, Malaysia. For multi-year level comparison, the survey was also offered to all third-year BPharmSc students in the same institution in Australia. In all instances there were no inducement offered as part of completing the survey. In all instances, the data was collected during a single year however multiple years levels are captured in this dataset.

Table 2-1. Descriptive statistics of surveyed cohorts for Bachelor of Science (BSc), Pharmaceutical Science (BPharmSc), and Pharmacy (BPharm).

	GENDER			AGE	DOMESTICITY		
	Female	**Male**	**Other**	**Avg. (S.D.)**	**Domestic**	**International**	**Total**
BSc (first-year)	102	59	3	18.40 (4.6)	143	21	164
BPharmSc (first-year)	73	51	-	18.74 (1.3)	81	43	124
BPharmSc (third-year)	36	21	1	20.97 (3.9)	44	14	58
BPharm (first-year AUS)	122	40	1	18.78 (1.1)	97	66	163
BPharm (first-year MYS)	93	22	-	19.55 (0.9)	108	7	115
Total	426	193	5	19.02 (1.3)	473	151	624

A total of 635 students responded with 11 cases being excluded due to missing data. A further 13 students opted not to provide demographic data. Details of the final sample of 624 students are shown in Table 2-1. Where students opted to not provide demographic data (gender, age, etc.), those analyses had a reduced sample size.

2.3.1 Analysis sample groups

In total, three analyses are to be conducted; motivation to attend university, motivation to choose a course, post graduation intentions. Each analysis will be conducted from three separate perspectives; international vs. domestic students, BSc vs. BPharmSc vs. BPharm students, Australian vs. Malaysian students. The schematic below indicates which cohorts contributed to which of the outlined perspectives.

In analysing domestic/international motivations and post-graduation destinations, we utilised the BSc, BPharmSc, and BPharm first-year survey results, from Australia only. The BPharm results from Malaysia were excluded from this analysis due to the difference in cultural backgrounds between the Australian and Malaysian domestic cohorts. These cultural differences may be an unintended confounding factor. The analysis of motivation to choose a course utilised the BSc, BPharmSc, and BPharm first-year survey results, from Australia only, excluding the third-year BPharmSc cohort to eliminate effects of exposure to the university system on any of the measures. Lastly, the comparison of student learning in Australia and Malaysia is limited to only the BPharm first-year cohort results from those countries due to sampling limitations.

Table 2-2. Schematic of cohorts used in analyses of student motivations and post graduation intentions.

	International vs. Domestic	BSc vs. BPharmSc vs. BPharm	Australia vs. Malaysia
BSc (first-year)	Yes	Yes	
BPharmSc (first-year)	Yes	Yes	
BPharmSc (third-year)		Yes†	
BPharm (first, Aust.)	Yes	Yes	Yes
BPharm (first, Malay.)	*		Yes

*In the analysis of domesticity, the Malaysian BPharm cohort was excluded due to the difference in cultural backgrounds between the Australian domestic cohorts and the Malaysian domestic cohort. A *domestic* student is defined as studying in their country of birth/residence, *i.e.* Malaysian nationals are *domestic* students in Malaysia and *international* students in Australia. †The third-year BPharmSc student responses were only considered in the analysis pertaining to post-graduation destinations. They were not analysed when looking at motivation to attend university, and motivation to choose a course.

2.4 Method

This study was conducted with approval by the institution's human ethics committee.

2.4.1 Data collection - survey

This research drew on the measurement tools developed by Henderson-King and Smith (2006) and Kennett *et al*. (2013) to define a set of student motivations. Both these studies have investigated similar research questions around student motivations to attend university. Students were asked to complete three questions; 'I chose to go to university because …', 'I chose to study this degree because …', and 'Imagine yourself six-months after you finish your degree. What do you want to be doing at this time?'. All questions were closed-response. The first two questions required the student to select the three most relevant responses from the prepared list and rank those in the order of their strongest to weakest motivation. The final analysis only considered their top response as being indicative of the most important rationale or reason regarding for the given prompt. The final question asked students to choose from further-study and job-related options. Provided responses are listed in Table 2-3 and response rates for each cohort indicated in Table 2-4. Students were lastly asked self-report their domestic/international status and other demographic details.

Table 2-3. Outline and classification of survey items.

Item	Classification
Question 1: Motivations to attend university*	
1.1 – It has been a lifelong dream to go to university.	intrinsic
1.2 – I did not want to get a job immediately.	extrinsic
1.3 – Going to university gives me more job opportunities.	extrinsic
1.4 – Society expects me to get a university degree.	extrinsic
1.5 – My friends are all going to university.	extrinsic
1.6 – I want to expand my social and professional networks.	intrinsic
1.7 – My family expects me to attend university.	extrinsic
1.8 – I didn't know what else to do / I didn't have anything better to do.	intrinsic
1.9 – I want to be challenged intellectually.	intrinsic
1.10 – I want to become independent from my family.	intrinsic
1.11 – I want to gain Australian permanent residency or citizenship.	extrinsic
Question 2: Reasons to choose your course	
2.1 – I had a high enough ATAR (university entrance) score.	study-related
2.2 – It is necessary for my desired career/job.	job-related
2.3 – I want to undertake a Masters or Doctoral degree in this subject area.	study-related
2.4 – I did not get directly into the Bachelor course I wanted.	study-related
2.5 – It will allow me to get a highly respected job.	job-related
2.6 – It will allow me to get a high-paying job.	job-related
2.7 – My teachers encouraged me to choose this degree.	people-related
2.8 – My family expects me to do this degree.	people-related
2.9 – I am interested in this area of study.	study-related
Question 3: Post-graduation intentions	
3.1 – Working in an industry related to this degree	working
3.2 – Working in an unrelated industry	working
3.3 – Completing another Bachelor Degree	studying
3.4 – Completing a Masters or Doctoral (PhD) Degree related to this degree	studying
3.5 – Completing a Masters or Doctoral (PhD) Degree NOT related to this degree	studying

*Classifications of intrinsic/extrinsic are derived from the inherent/extrinsic motivations model of Ryan and Deci (2000).

Table 2-4. Question response rate by cohort (first-year respondents only)

	DOMESTICITY†		COURSE			COUNTRY	
Response*	**Domestic**	**International**	**BSc**	**BPharmSc**	**BPharm**	**Australia**	**Malaysia**
1.1	39	12	21	13	25	17	8
1.2	1	2	2	1	2	-	2
1.3	145	42	63	68	101	56	45
1.4	12	7	3	2	25	14	11
1.5	1	1	-	-	3	2	1
1.6	28	19	14	11	40	22	18
1.7	13	6	6	4	14	9	5
1.8	5	4	1	3	5	5	-
1.9	57	23	40	18	33	22	11
1.10	19	12	14	3	26	14	12
1.11	1	2	-	1	4	2	2
Total	321	130	164	124	278	163	115
2.1	18	3	5	7	14	9	5
2.2	49	20	16	24	50	29	21
2.3	22	6	15	5	9	8	1
2.4	27	8	14	6	15	15	0
2.5	21	15	7	10	32	19	13
2.6	14	13	4	11	28	12	16
2.7	2	1	1	-	2	2	-
2.8	4	2	1	-	17	5	12
2.9	164	62	101	61	111	64	47
Total	321	130	164	124	278	163	115
3.1	184	62	67	71	198	108	90
3.2	9	-	4	1	4	4	-
3.3	14	1	8	2	5	5	-
3.4	94	62	74	43	60	39	21
3.5	15	4	7	6	6	6	-
Total	321	130	164	124	278	163	115

*Response rates only include first-year students from the BSc, BPharmSc, and BPharm (Australia and Malaysia). Third-year data is not included in these totals.

†In the response counts under domesticity, the Malaysian BPharm cohort was excluded due to the difference in cultural backgrounds between the Australian domestic cohorts and the Malaysian domestic cohort.

Ideally the survey was to be completed as close to the start of the first semester of the new year to reduce exposure to the university system and their degree program. We suggest that this may reduce any potential for bias and priming that may derive from their educational experience. Additionally, this would capture their motivations as close as possible to the point at which they made the decision to attend university and to choose their specific course. The students studying in Australia completed the survey within the first three weeks of the university first semester (during orientation non-teaching week, first-, and second week of studies). Due to timing restrictions, the students in Malaysia were surveyed during the first week of the second semester.

2.4.1.1 Translations

Due to the expected large number of international students in cohorts, we had the survey translated into Simplified Chinese and French as these two languages are two of the main languages in addition to English, as indicated by students studying at Monash University. The Chinese version of the survey was translated by three native Mandarin speakers, all of whom have lived in China for between 10–20 years, and lived in Australia for between 5–15 years. Through two rounds of translation, discussion with the principal researcher, and a review by each of the speakers, we are confident that the expression and intention of the Chinese translated version was clear and matched that of the English original version. Likewise, the French version was translated by a professional translator who is a French native.

2.4.2 Data collection - graduate destinations

The Australian Government Department of Education and Training conducts an annual survey of graduating students, including undergraduate and postgraduate students. The *Graduate Outcomes Survey* (GOS) collects, among other data, the employment outcomes of graduates across Australia. This data is reported for courses at each Australian higher education institution.

It is important to ensure that this data is representative. While there is no information on response rate for specific courses or areas of study, the overall response rate for Monash University was 48.8% (Social Research Centre, 2019, p. 118). The overall response rate for Monash University is slightly higher than the response rate at all institutions for the fields of ‘science and mathematics’ (46.6%) and ‘pharmacy’ (41.1%) (Social Research Centre, 2019, p. 121). The GOS report however states that the profile of the respondents is representative of the GOS population (Social Research Centre, 2019, p. 119).

As a supplement, the institution *Alumni Engagement Office* provided graduate employment data for BPharmSc graduates only. This data is pulled from publicly-available sources, predominantly the LinkedIn platform. This data covers all students graduating from the faculty from 2008 onwards. For the purpose of this research, data were collected on students who finished their course at the end of 2016 and end of 2017. The data aligns with the above GOS data.

2.4.3 Analyses

Chi-squared tests of independence were undertaken to assess potential statistical associations amongst our measurement groups. The independent variables were domesticity (international, domestic), course (BSc, BPharmSc, BPharm), and country of study (Australia, Malaysia). The dependent variables were motivation to attend university (intrinsic, extrinsic motivator), reason to choose their course (job-, people-, study-related reason), and intended destination after graduation (further study or employment). In each case a statistically significant result would indicate an association between the groups of interest. Statistical analyses were conducted using IBM SPSS Statistics 24 (SPSS Inc., Chicago, IL).

2.4.4 Representativeness and missing data

Chi-square goodness-of-fit tests were conducted on the BPharmSc and BPharm cohorts to determine the representativeness of each sample to the entire population. The tests used gender, domestic/international status, and language spoken at home (English or non-English) as variables. In each case, the $p > 0.05$ indicating that the samples statistically representative of the full sample population, based on these measures. Due to lack of data and low response rates, no such test could be performed on the BSc cohort. For all cohorts, the age of the students was within one standard deviation of the population median age. There was a range of response rates from each cohort, with the highest being BPharmSc (first-year 88.6% response, third-year 67.8%), then BPharm (Australia 83.2%, Malaysia 92.0%), and BSc (12.4%). The BPharmSc and BPharm responses are taken to be representative, while the BSc responses are likely unrepresentative, but provide a general indication of responses.

The graduate employment data is fully representative as it captures the entire BPharmSc graduating cohort of 2016 and 2017 (graduating in the middle of the following calendar years). Of the full cohort (n = 110), only a small number of employment details could not be found (n = 3, 2.7%) and were treated as ‘unknown respondents’ and retained in the analysis.

2.5 Results and discussion

The purpose of this study was to examine (i) potential differences in motivations to attend university, (ii) potential differences in reasons to choose a course, and (iii) intended post-graduation outcomes between generalist/vocational students, domestic/international students, and Australian/Malaysian domiciled students. The first two points shall be presented and discussed in tandem, followed by the results and discussion of the third point.

2.5.1 Motivation to attend university, and reason to choose a course

We present the results of the analyses of respondent motivation to attend university, and reason to choose a course together. Key findings and points of discussion follow.

Results from the chi-square tests for independence for ‘motivation to attend university’ are shown in Figure 2-1.

There was no statistically significant association for the domestic/international comparison with intrinsic/extrinsic motivation to attend university. However, the more vocationally-oriented courses were associated with increased extrinsic motivation, as compared to the generalist BSc course. Again, in the case of Australia and Malaysian courses, there was no statistically significant association for the domestic/international comparison with intrinsic/extrinsic motivation to attend university.

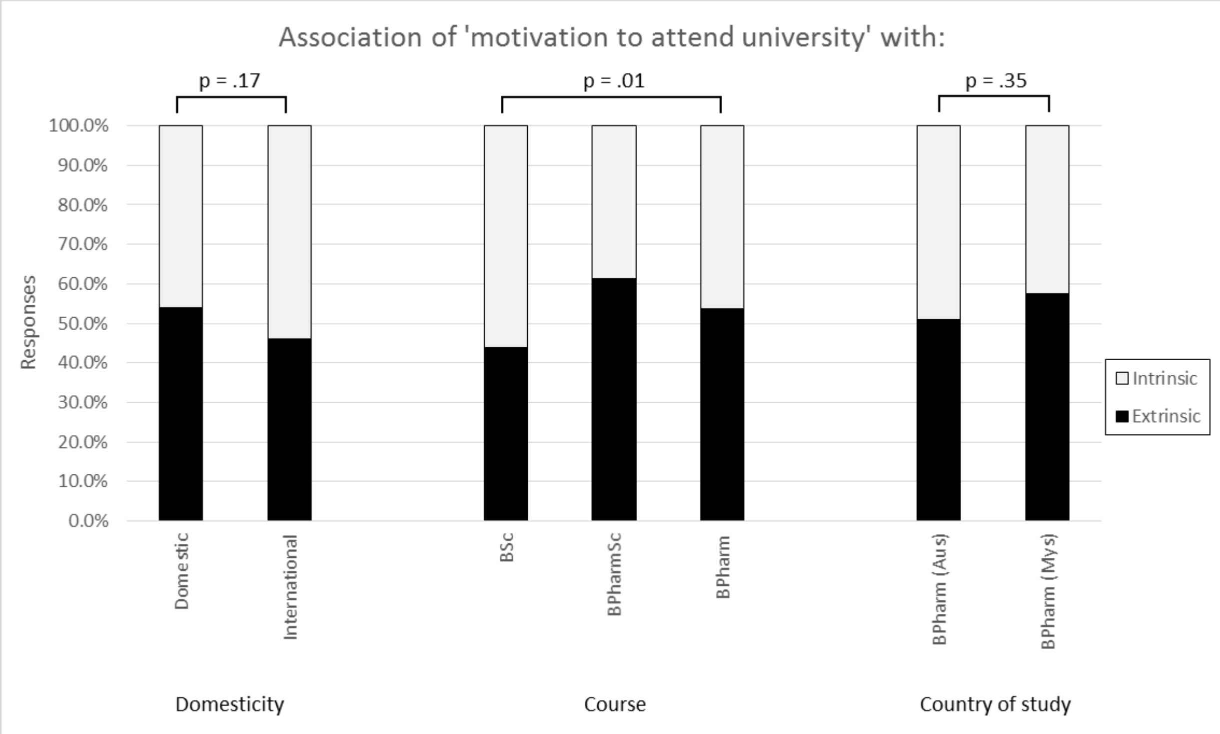

Figure 2-1. Chi-square associations of domesticity, course of study, and country of study with intrinsic/extrinsic motivation to attend university for first-year students only.

Domesticity x Motivation: χ^2 Yates' Continuity Correction (1, n = 451) = 1.92, p = .17, phi = -.07.

Course x Motivation: χ^2 (2, n = 577) = 8.67, p = .01, Cramer's V = .13.

Country of study x Motivation: χ^2 Yates' Continuity Correction (1, n = 278) = .89, p = .35, phi = .64.

Note: Yates' Continutity Correction is applied to 2x2 χ^2 analyses as suggested by Pallant (2016). Cramer's V is a post-test measure to determine the strength any significant relationships determined using χ^2 analyses. This is only applied to analyses greater than 2x2. This approach is detailed in Pallant (2016).

Table 2-5. Major responses for 'motivation to attend university' from each category indicating response rates from each cohort (as a percentage of all responses from that cohort)

	Extrinsic motivation *'more job opportunities'*	Intrinsic motivation *'intellectual challenge'*
Domestic	145 (45.2% of domestic responses)*	57 (17.8%)*
International	42 (32.3% of intl. …)	23 (17.7%)
BSc	66 (37.7%)	43 (24.6%)
BPharmSc	68 (54.8%)	18 (14.5%)
BPharm	101 (36.3%)	33 (11.9%)
BPharm Australia	56 (34.4%)	22 (13.5%)
BPharm Malaysia	45 (39.1%)	11 (9.6%)

* Domestic/international categories have no statistical association with extrinsic/intrinsic motivations; they are statistically independent of each other and are non-predictive.

The chi-square analysis only considers the students' first response showing little variation between groupings. Notably, the next highest options selected for each cohort was varied. Domestic students were more likely to select 'lifelong dream to attend university' (n = 39, 12.1%) as a major intrinsic reason to enrol in university whereas international students were more likely to indicate 'expansion of social and professional networks' (n = 19, 14.6%) as a major intrinsic reason to enrol. Comparing the three courses, BSc and BPharmSc indicated 'lifelong dream' (n = 24, 13.7%; 13, 10.5% respectively) and BPharm indicated 'independence from family' (n = 26, 9.4%), both intrinsic reasons. Expansion of networks also featured prominently in the Malaysian cohort responses (n = 18, 15.7%), outpolling the view of intellectual challenge.

Results from the chi-square tests for independence for 'reason to choose a course' are shown in Figure 2-2.

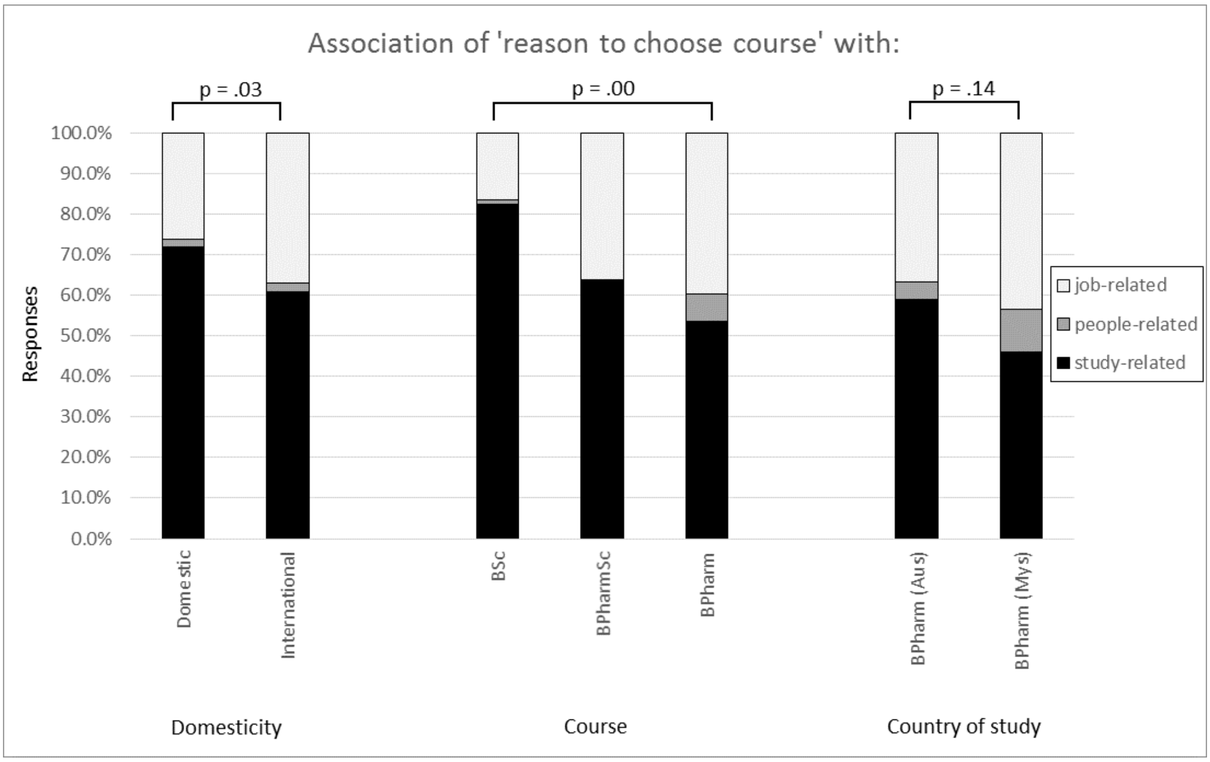

Figure 2-2. Chi-square associations of domesticity, course of study, and country of study with job-, people-, and study-related reasons to choose a course for first-year students only.

Indicated p-values are calculated excluding the ‘people-related’ category.

Domesticity x Reason: χ^2 (1, n = 442 [excluding ‘people-related’]) = 4.83, p = .03, phi = -.11.

Course x Reason: χ^2 (2, n = 545 [excluding ‘people-related’]) = 40.0, p = .00, Cramer’s V = .19.

Country of study x Reason: χ^2 (1, n = 259 [excluding ‘people-related’]) = 2.19, p = .14, phi = -.10.

Note: Cramer’s V is a post-test measure to determine the strength any significant relationships determined using χ^2 analyses. This is only applied to analyses greater than 2x2. This approach is detailed in Pallant (2016).

For the purpose of analysing ‘reason to choose a course’, the ‘people-related’ grouping was excluded due to low response rates when looking at domesticity and course comparisons. For consistency of analyses, the analysis of people-related reasons for country of study was not conducted. These people-related reasons include teacher and family pressures to choose a specific course. Comparing domestic and international respondents, significantly more international students cited job-related reasons than their domestic peers (36.9% and 26.2% of all responses, respectively). Comparatively, moving from generalist science course to vocational pharmacy course shows a clear and moderate strength (Cohen, 1988) shift towards job-related reasons, although study-related responses still dominate. The Malaysian cohort had a larger proportion of people-related motivation, mostly around family expectations, as noted below.

Table 2-6. Major responses for 'reason to choose a course' from each category indicating response rates from each cohort (including 'people-related category', as a percentage of all responses from that cohort)

	Study-related *'interesting study area'*	Job-related *'job necessity'*	People-related *'family expectation'*
Domestic	164 (51.1% of domestic responses)	49 (15.3%)	4 (1.2%)
International	62 (47.7% of intl. …)	20 (15.4%)	2 (1.5%)
BSc	101 (61.6%)	16 (9.8%)	1 (0.6%)
BPharmSc	61 (49.2%)	24 (19.4%)	17 (6.1%)
BPharm	111 (39.9%)	50 (18.0%)	0 (0.0%)
BPharm Australia	64 (39.3%)	29 (17.8%)	5 (3.1%)
BPharm Malaysia	47 (40.9%)	21 (18.3%)	12 (10.4%)

2.5.1.1 Student motivations to attend university and to choose a course present a mixed picture

In considering student motivation to attend university, there is no significant association between domestic/international status and intrinsic/extrinsic motivation. In both cases a desire for more job opportunities was the most cited motivator (extrinsic), with a desire for intellectual challenge being the most cited intrinsic motivator. The top-cited extrinsic and intrinsic motivators remained the same when comparing vocational and generalist degrees. Curiously there is little difference between BSc and BPharm when indicating extrinsic (44.0% and 46.4% respectively) or intrinsic (56.0% and 53.6% respectively) motivation to attend university. However, BPharmSc has a much higher proportion of extrinsic motivation (61.3% of all responses), of which the desire for more job opportunities comprised the majority of responses (54.8% of responses of the 61.3% of all responses). These results support prior research in this field. The uptick in extrinsic motivation when comparing BSc and BPharmSc is expected based on employment data comparing vocational and generalist courses (Social Research Centre, 2019). While BPharm students indicate a small increase in extrinsic motivation compared to BSc (44.0% to 53.6%), there is no expected increase when comparing BPharmSc and BPharm. These data would suggest that it is erroneous to consider BPharm to be a more vocationally-oriented form of the BPharmSc and that BPharm students are attending university for similar reason as BSc students but may be choosing the BPharm course for different reasons compared to the BPharmSc. Meanwhile, Malaysian student reasons to attend university and to choose a course were not statistically significantly different from their Australian counterparts.

2.5.1.2 A desire for more job opportunities not reflected in reason to choose a course

While students often cited an overall motivation to improve their job prospects, far fewer saw their course as a necessity for their chosen job instead noting an interest in the area of study as the main reason. We posit that this is due to student interpretation of the prompt. A student who chooses to study the BPharmSc may 'enjoy chemistry as an area of study' rather than 'enjoy pharmaceutical sciences as an area of study'.

In choosing their course, there is an association between domestic/international status and their cited motivation. More international students report a job-related reason to choose their course compared to domestic students (36.9% and 26.2%, respectively). However, study-related reasons still comprise the bulk of cited reasons, specifically interest in the area of study. A similar result is found in comparing vocational and generalist degrees. Most notably BSc students cite more study-related reasons for choosing their course. Of BSc students, 82.3% selected a study-related reason, in which three-quarters of all responses related to interest in the area of study (62.0% of the 82.3%). Unexpectedly, BPharm students did not strongly indicate that they chose their course as it is a necessity for their career. While 39.9% of responses indicated an interest in the area of study, only 18.0% indicated choosing the course primarily due to it being a necessity for a career as a pharmacist, even though it is a legal prerequisite in both Australia and Malaysia. This finding was observed in both the Australian BPharm students (17.8%) and Malaysian students (18.2%).

Allowing for the limited BSc response rate, it does appear that our findings do reflect previously conducted research in this area. The higher-than-expected extrinsic motivations for the BPharmSc does highlight that this course, while less specialised than the BPharm equivalent, would require a shift away from a focus on the acquisition of knowledge as an end-goal and a greater focus on employment outcomes or applications of knowledge within the workplace. Although not demonstrable in this dataset, we are led to ask whether the vocational/generalist differences among courses will, in general, lead to a greater job focus.

2.5.1.3 Opportunities to use employment and networking to motivate students

One clear response from international students and BPharm students in Australia and Malaysia was the desire to expand their social and professional networks. While responses from international students indicate that this expansion of networks may weigh more heavily on the social network side (Sawir *et al*., 2007), opportunities to expand professional (including academic) networks should not be ignored, especially where networking has ramifications for future employment or research opportunities. As will be shown shortly, international students are significantly more likely than their domestic peers to want to continue on to further study.

From all the cohorts sampled, educators can definitely rely on an initial interest in the study area as a way to motivate their students. Whether these thoughts can be turned towards post-graduation employment remains to be seen. As becomes clear from the following analyses, a large proportion of students will be entering the workforce after completing their degree.

2.5.1.4 Malaysian students are more collectivistic than Australian students

A larger proportion of Malaysian students studying BPharm cited people-related reasons for choosing their course than Australian BPharm students. Overall, 10.2% of Malaysian student responses (n = 12) cite family expectations as reason to choose their course. Comparatively, 3.1% of Australian students (n = 5) cite the same reason, with a further two Australian respondents (1.2%) citing teacher encouragement. Interestingly though, of the five Australian respondents citing family reasons, two are international students, and two are domestic students from non-Anglo backgrounds as indicated by a language other than English as the primary household language. While an interesting observation, these results must be taken in the context of the larger international cohort of BPharm studying in Australia. The majority these come from S.E. Asian countries. Of the international students studying BPharm in Australia, 55% still cited study-related reasons, and a further 41% cited job-related reasons.

It would appear that students studying in Malaysia (of which 94% are Malaysian nationals or permanent residents) do exhibit a greater family-oriented motivation to choose their course when compared to students studying in Australia (60% are Australian nationals or permanent residents). It is curious that the family-related reasons seem to disappear or are tempered once students move to Australia to complete their studies. This study is not sufficiently in-depth to challenge this observation and so remains a potential avenue for future research.

2.5.2 Post graduation intentions

Results from the chi-square tests for independence are shown in Figure 2-3.

There is a clear tendency for domestic students desire to end up working rather than pursuing further study. Additionally, those in more vocationally-aligned degrees and those studying in Malaysia have a clear and moderately strong (Cohen, 1988) statistical intention towards working.

By way of comparison, the third-year students from the BPharmSc course showed the greatest intention to enter the workforce. A chi-square goodness-of-fit test indicates no significant difference in the proportion of students *intending* to enter the workforce, as compared to *actual* proportion of students entering workforce twelve-months post-graduation, as obtained from alumni data from 2016–2017 (the latest full data available). Of those currently in third-year, 45 intend to enter the workforce (78.9%) and 12 intend to pursue further study (21.1%). The 2016–2017 data suggests less graduates entering the workforce (n = 74, 67.3%) and more studying (n = 33, 30.0%), with three missing data points. Data from the government-collected Graduate Outcomes Survey (GOS) for 2017 indicates that twelve-months post-graduation sees a national employment rate for 'pharmacy' of 95.2%, and for 'science and mathematics' 59.0% (Social Research Centre, 2019). The pharmaceutical sciences are subsumed under the 'science' category.

In summary, twelve-month employment rates for each course are; Bachelor of Science (nationally, GOS data) 59.0%, Bachelor of Pharmaceutical Science (Monash-only, faculty data) >67.3%, Bachelor of Pharmacy (Australia-only nationally, GOS data) 95.2%.

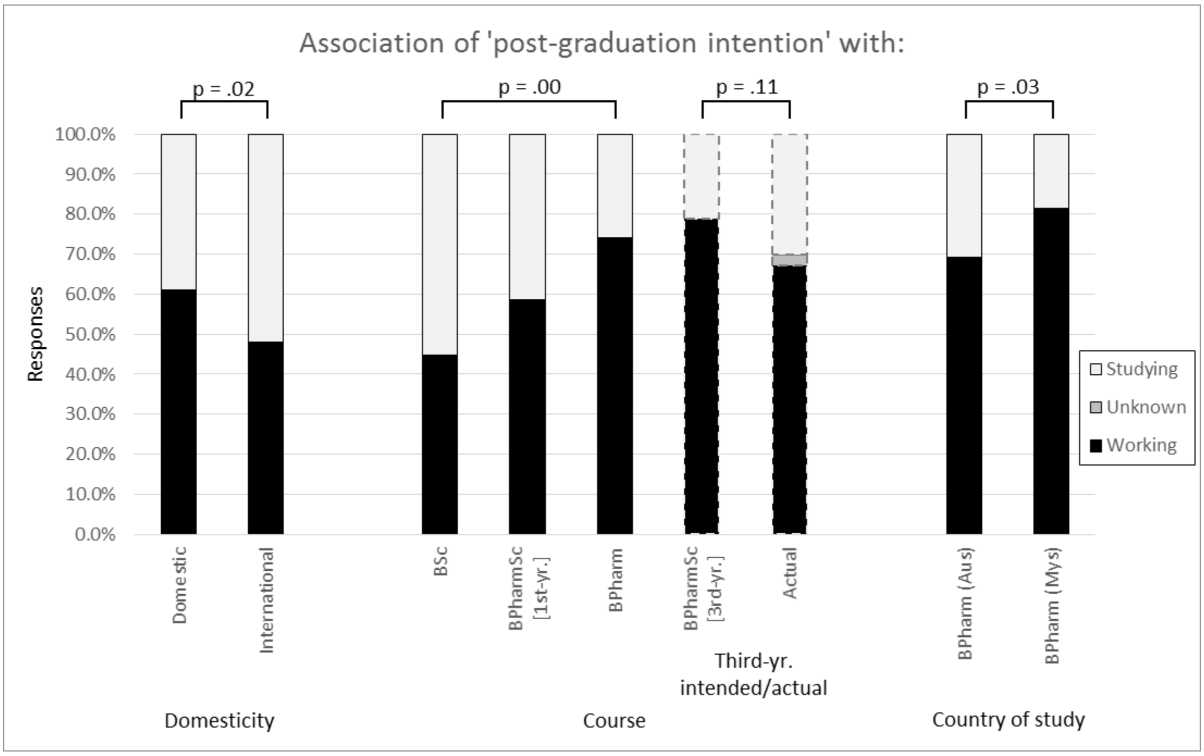

Figure 2-3. Chi-square associations of domesticity, course of study, and country of study with post-graduation intentions for first-year students only.

Sub-plot of third-year BPharmSc student intentions and actual historical post-graduate destinations for that same cohort.

Domesticity x Intention: χ^2 Yates' Continuity Correction (1, n = 445) = 5.82, p = .20, phi = .12.

Course x Intention: χ^2 (2, n = 559) = 38.4, p = .00, Cramer's V = .26.

Third yr. intended/actual: χ^2 goodness-of-fit (1, n = 57) = 2.56, p = .11.

Country of study x Intention: χ^2 Yates' Continuity Correction (1, n = 275) = 4.62, p = .03, phi = -.14.

The difference between Australian and Malaysian student intention to enter the workforce also warrants further study. Of the Australian BPharm students, domestic Australian students were far more likely to want to enter industry than their international counterparts (77%, n = 75; 57%, n = 37). Comparatively, the Malaysian BPharm domestic students were more similar to the Australian domestic students in wanting to enter industry (78%, n = 84). The observed statistical difference between Australian BPharm and Malaysian BPharm student intentions is in fact driven by the large proportion of international students in the Australian BPharm who intend to undertake further study. This may be in part due to social and cultural expectations of the international students coming to study in Australia. Anecdotal evidence suggests that international students studying BPharmSc and BPharm in Australia intend to go continue on to further studies in order to secure a higher degree before entering the workforce. With the perception of an increasing number of Bachelor and Master qualified graduates, the Ph.D. is perhaps seen as a means to standing out in a crowded marketplace if they choose to return to their home countries for employment. This may be especially true at Monash University due to its strong research focus and high international ranking. As such we suspect the finding that international students intending to pursue further study would be replicated at other research-intensive (and internationally highly-ranked) institutions. These findings are derived from informal conversations conducted at the authors' home institution final final-year international undergraduate students, and first-year international Ph.D. students. This particular area of inquiry would appear to deserve further investigation in a separate piece of work.

2.5.2.1 Specialised courses tend towards higher employment

The pattern between increasingly vocational courses and increasing intention to enter the workforce reflects the research of Fenesi and Sana (2015) looking at Canadian students in which those graduating from specialist science, technology, engineering, mathematics, and medicine (STEMM) programs are more likely to be engaged in full-time employment than their generalist humanities, arts, and social sciences (HASS) peers. Unfortunately, in the Australian context there is little comparative research other than government-published data showing the top study areas with full-time employment are specialised courses (clear vocational outcome); pharmacy, medicine, physiotherapy, building/construction, civil engineering. Comparatively the bottom five study areas are generalised courses; medical sciences, biological sciences, tourism/hospitality, performing arts, art/design.

2.5.2.2 Opportunities to embed increased work-focus during course

Results from our study clearly reflect the trend for specialised courses that lead to employment. It would appear that students in these vocationally-focused courses have the greater ambition to enter the workforce rather than to continue studying. By comparing the BPharmSc first- and third-year respondents, there is a clear trend towards intention to enter the workforce. Unfortunately, this study did not investigate the final-year workplace intentions of BPharm or BSc students and so no general comment can be made regarding course progression and intention to enter the workforce. We do note however that the employment rates of BSc and BPharm graduates in Australia are higher than these first-year intentions would indicate (Social Research Centre, 2019). Assuming that the rates of employment from these cohorts was to meet previously reported levels, then the BPharm and BSc cohorts would likely reflect an increase in intention to be working post-graduation over their degree, similar to the increase shown during the BPharmSc course. This may indicate an opportunity for educators in the early years of these degrees and for high-school careers advisors to better highlight the potential and probable job outcomes of these students.

With a marked increase of BPharmSc students desiring to enter the workforce over the duration of their course, it may be beneficial to provide more workplace-aligned teaching and skills development early in the course to provide students the opportunity to sufficiently develop workplace skills prior to graduation. This is especially pertinent for a course like BPharmSc that is not vocationally-oriented but whose students have a clear desire for employment. Educators in other fields with similar properties need to ensure that students are being sufficiently prepared for where they intend to be after graduating. If educators are able to build on student interest in the area of study by contextualising their learnings to the workplace environment throughout the course, educators can develop student workplace-relevant skills prior to them graduating. Such an approach has previously been found to be favoured by employers in an Australian STEMM context (Pearl, Rayner, Larson, & Orlando, 2018; Sarkar, Overton, Thompson, & Rayner, 2016).

2.5.2.3 Opportunities for skills development in international students

As international students and BSc students have a stronger intention towards further study, this presents an opportunity for educators and support services to target these groups (including other generalist courses) to either promote further study opportunities or to highlight research-based job options within private and public industry. We suspect one explanation for this difference between international and domestic students lies with the Australian visa system which allows those continuing to study to remain in the country without the complexity of having an employer sponsor a work visa. Again, these observations derive from informal conversations conducted with international students at the authors' home institution. A further investigation into the prevalence and depth of these sentiments should be considered. With the potentially limited research positions, faculties may need to reflect on the availability of high-quality research options offered to students both during their course and as postgraduate studies. This will require greater engagement with industry, greater opportunities for work-integrated learning (WIL), both of which should enhance work opportunities.

2.6 Limitations and further work

As with any self-reported measures, this study must consider self-report response bias as a potential source of error, especially social desirability (the tendency to present oneself as aligned with cultural norms) (Donaldson & Grant-Vallone, 2002; Van de Mortel, 2008) and recency (where the most recent presented options are more likely to be presented than earlier ones) (Krosnick, 1999). In limiting the former, the students were reminded that the survey was anonymous and would have no bearing on their grades. Data collection was completed by non-teaching researcher and demographic data were collected after the main survey questions were completed (and could not be revisited). Additionally, in addressing the latter concern, we do not believe that recency would have substantial effect on the BSc, BPharmSc (first-year) and BPharm (Australia) cohorts who underwent data collection as close to start of first teaching semester as practicable. This should allow for their true motivations to be better probed. The BPharmSc (third-year) cohort naturally has been exposed to much greater university teaching and so their motivations were not compared. However, their post-graduation career intentions are more realistic than their first-year counterparts. As researchers we would have preferred a larger response rate from the BSc cohort to increase our confidence of data representativeness. In addressing recency, providing shorter lists of options that can be viewed on one page or one screen reduces the likelihood of selecting either the first or last options. Additionally, students were required to pick three most applicable option and then to rank them in order of applicability to their situation. This deliberate reflective exercise encourages students to engage more deeply with the content.

In surveying so many students, it was practical to use a set of closed-response questions. A good follow-up would include a set of focus groups from each cohort to determine whether student responses reflect their true intentions. In general, this research area would benefit from a larger, multi-program study to investigate whether these findings are translatable more broadly across other STEMM and non-STEMM disciplines. Further work should also consider the alignment of university course and required job skills from both generalist and vocationally-oriented courses. Some research in this area does indicate a moderate correlation between ‘generalist’ and ‘single-focus’ science courses and utilisation of acquired skills during employment, in that the single-focus science courses tend to lead to increased self-reported use of university-acquired skills in the workplace (Anderson, McInnis, & Hartley, 2003). It remains to be seen whether these results are translatable across multiple disciplines.

Further research into the differences and similarities between international and domestic students studying the same course in different countries is warranted due to the findings around the BPharm students from Australia and Malaysia. With a better understanding of these similarities and differences, institutions will be better able to recruit and accommodate students from other regions.

2.7 Conclusion

Empirical studies have previously found that STEM-based courses typically result in higher employment rates post graduation. Our work looks deeper into this phenomenon by considering vocationally-aligned and generalist STEMM courses specifically. This study found that students are choosing to enrol in tertiary education primarily to improve their job opportunities. However, their specific course choice is dependent on personal interest in the particular area of study. Educators should capitalise on this to provide students with learning opportunities within their field that are aligned with potential job outcomes. In increasingly vocationally-oriented courses, educators should be aware of a higher intention to enter the workforce after graduation. This may be increasingly true as students progress through their degree, potentially shifting their intentions towards post-graduation employment rather than further study. Different educational opportunities exist for international students who have a greater intention continue further study.

Postface

Considering only the students of the Bachelor of Pharmaceutical Science, the findings from this chapter show us that there is a non-negligible proportion of students who are choosing to attend university in order to improve their job prospects. This is also indicated when looking across the duration of the course. The proportion of students wanting to enter the workforce increases consistently. Focusing on those students who want to enter the workforce, we turn now to understanding critical thinking in the context of the workforce.

Chapter 3

Industry Conceptualisations of Critical Thinking

Preface

In the previous chapter we saw that a large proportion of students from the Bachelor of Pharmaceutical Science who intend to enter the workforce after graduation. As we previously discussed, industry is keen to recruit graduates that display stronger critical thinking (CT) skills. What is less clear, however, is how industry understands (or conceptualises) CT. For the purposes of this dissertation we are only interested in those industries that recruit graduates from our course. While our graduates have previously entered a wide range of industries, let us now only focus on those industries whose primary business activities are directly related to our course. This chapter comprises a study in which we aim to understand these industries' conceptualisation of CT within their business context.

Chapter Contents

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Thinking about critical thinking: Industry perspectives

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Abstract

There has been a drive towards enhancing critical thinking (CT) skills development of students in the science, technology, engineering and mathematics (STEM) disciplines, both in Australia and internationally. One debate amongst CT theorists centres on whether CT comprises a set of generalisable skills or is content- and context-dependent. While previous studies have considered CT skills development and its assessment in pharmacy courses, there appears to have limited scholarly research within the pharmaceutical science discipline. In seeking to address this, it is vital to understand how appropriate companies conceptualise CT and its use by Bachelor of Pharmaceutical Science graduates. This research identified five major categories used to conceptualise CT within interviewed companies; *being systematic*, *having strong business-sense*, *considering multiple-solutions*, *considering implications*, and *identifying problems and potential solutions*. This study found that while these skills are dependent on the business context, they may be more generalisable across a range of industries.

3.1 Introduction

In recent years, critical thinking (CT) has increasingly become an in-demand trait for graduates of science, technology, engineering, mathematics, and medicine (STEMM) disciplines, both locally in Australia and internationally (Flores *et al*., 2012; Maxwell *et al*., 2010; Oliver *et al*., 2010; Osmani *et al*., 2017; Prinsley and Baranyai, 2015). Recent studies have reported that students (Canadian University Survey Consortium, 2017), and some industries (ABS, 2006 as cited in Norton & Cherastidtham, 2016) view a university education as a means to secure more rewarding and highly paid employment. Previous research has also shown a correlation between a formal education and development of reasoning skills (Ding, 2017), often through participation in experiential programs (Hannon, McBride, and Burns, 2004). Development of such reasoning skills feeds back into content learning (Kuhn *et al*., 2000; Lawson, 2004). Moreover, CT is considered as fundamentally important for fully engaged citizens in a modern world (Halpern, 1998; ten Dam and Volman, 2004). Ten Dam and Volman argue in favour of a 'social constructivist' approach in defining CT through having a greater quality of participation in society. Ten Dam and Volman consider CT in the context of "[participating] critically in the communities and social practices to which a person belongs." To complement this conceptualisation of CT, the empirical research below considers the conceptualisation of CT in the context of the workplace.

3.1.1 Conceptualising critical thinking

CT is seen as a higher level of thinking; more than just thought (Ennis, 2015). Among modern conceptions, CT has been considered as a 'purposeful act' (Halpern, 1998) of 'reasonable and reflective thinking' (Ennis, 1993) in the form of a series of actions that a critical thinker undertakes. Facione (1990) outlines one such approach in his seminal publication *The Delphi Report*. By way of consensus, he brings together many perspectives to define CT as a set of actions that a critical thinker undertakes, such as 'analysis', 'evaluation', and 'inference'. He further expands this idea by also considering one's disposition towards using CT skills. That is to say that it is not sufficient that one knows how to think critically, but that they are inclined to think critically when appropriate. Paul and Elder (2008) also suggest the inclusion of 'intellectual criteria' or standards defining how well these actions should be conducted in order to be considered a good critical thinker (for example: logically, clearly, and precisely).

This research integrates the CT competencies (cognitive skills and dispositions) of Facione (1990) and (the intellectual criteria) of Paul and Elder (2008).

3.1.2 Context-specificity and transferability of critical thinking

There is ongoing debate about the ability of a learner to take CT competencies developed in the classroom and apply (transfer) them spontaneously in novel situations (Ennis, 1989; McPeck, 1990; Perkins, and Salomon, 1989) or even the degree to which this transfer of skills is currently being done (Davies, 2016). The discussion around transferability is intimately linked with the debate around generalisability of CT skills in that without transferability, CT skills would therefore be unable to be generalisable outside a classroom setting. Halpern (1998) describes the goal of instruction in CT techniques as being able to transfer these skills out of classroom into "real-world" settings. One method to address this may be through a constructivist approach in which knowledge is constructed through interaction with phenomena (Watts, Jofili, and Bezerra, 1997). In this case, the phenomena to which students would need to be exposed would be in-context CT. To this end, CT would be an ideal candidate for a constructivist approach in that a 'critical constructivism' concerns itself with "complex multi-layered circumstances which entail, for instance, awkward or unresolvable issues which cannot be tackled easily" (Watts, Jofili, and Bezerra, 1997). The complexity of these 'circumstances' and 'issues' align with the types of CT problems envisaged by social constructivists like ten Dam and Volman, amongst others.

The inability of students to recognise the appropriateness of their CT skills in novel situations (Bransford, Brown, and Cocking, 2000; Halpern, 1998) may limit the transferability. One way this may be addressed is through the use of authentic scenarios in teaching and assessment that reflect a situation in which the student would be required to utilise their CT skills. Bransford, Brown, and Cocking (2000) discuss such ideas by describing how students may be presented with a specific task in one specific context before being presented with another, similar context. This, they posit, enhances student ability to identify which general principles can be transferred. One way this concept may be applied is through a valid or realistic representation of the situation in which the student would be expected to use the desired skill. The use of authentic tasks, particularly in assessment, is supported by the work of Lund (1997), who described how well-developed authentic assessments can induce higher-order thinking (including CT). She describes 'well-developed authentic assessments' as characterising, amongst others, the following traits; (1) meaningful tasks that simulate the real-world tasks, (2) the aim to elicit higher level thinking rather than rote memorisation, (3) clearly articulated assessment criteria, (4) formative, rather than summative assessment, (5) assessment of the thought process as well as the end products. Lund argues that through this, the assessor is able to detect, for example, "faulty logic … [that] could mean wrong decisions in future…" (Lund, 1997). One study has indicated a moderate improvement in CT skills by teaching using authentic tasks (Colletti, 2011). However, what is not clear in this instance was the degree to which these developed CT skills are themselves transferable.

Other promising methods of overcoming the issue of transferability have been reported. One such example is detailed by Helsdingen, van Gog, and van Merriënboer (2011) in participants were assigned to either regular or random schedules for practicing on "complex judgement tasks". These schedules were supplemented with post-practice CT prompts which lead to substantial performance gains on these "complex tasks". The specific teaching of CT also appeared to have a beneficial effect on economics students' reasoning skills (Heijltjes *et al*., 2014).

3.1.3 Discipline-specific critical thinking

Many disciplines have considered CT (or an allied concept) as a key employability marker. Taking engineering as an example, van der Wal, Bakker, and Drijvers (2017) look into the 'techno-mathematical literacies' required of modern engineers. While not explicitly articulating 'critical thinking', they do discuss 'data literacy' and a 'sense of error' as key skills. Most tellingly, they describe these literacies as abilities to "analyse", "interpret", "draw conclusions", and "check and verify". This conceptualisation is very much in the language used by Facione (1990), and later by Paul and Elder (2008). Other disciplines have developed a context-specific test of CT ability for measuring the degree to which their courses instil CT into their students. For example, in the nursing field, the *Health Sciences Reasoning Test* (HSRT) has been used extensively to assess CT skills in undergraduate courses (Hunter, Pitt, Croce, and Roche, 2014). The HSRT focuses on those skills outlined by Facione (1990) (*i.e.* interpretation, analysis, evaluation, inference, explanation, self-regulation) in "clinical and professional contexts" (Insight Assessment, 2016). Interestingly, the HSRT has also been trialled as a pre-admission diagnostic test for pharmacy (Kelsch and Friesner, 2014). Although there are some similarities between a pharmacy course and the pharmaceutical sciences, it would appear that this test was primarily intended to address the CT skills used when handling patients (pharmacy practice) rather than those used in drug discovery and formulation (pharmaceutical science). This test thus appears to be *industry-aligned* for pharmacy but not for the pharmaceutical sciences. Again, there does not appear to be a specific test for pharmaceutical sciences; no test addresses *industry-aligned* CT as it would be undertaken in industries that employ graduates from pharmaceutical sciences courses. This perhaps indicates a potential avenue of exploration, development and evaluation of such a test.

3.1.4 Critical thinking in the pharmaceutical sciences context

Graduates from our undergraduate pharmaceutical science course typically go on to employment within pharmaceutical and consumer goods companies. A most direct approach to understanding how CT is conceptualised by these industries is to query them and look for those concepts that can be considered as CT by comparing them against currently accepted understandings of CT. While studies into CT skills development have been conducted in many educational areas, including pharmacy (Gleason *et al*., 2013; Peeters and Boddu, 2016), a search of the literature has not uncovered any studies to date that look at CT competencies in undergraduate pharmaceutical science students. This gap in the literature is encouraged by work that found benefit for each stakeholder group in linking industry experience with the educational setting, such as benefitting industry through access to strongly developed graduates (Brunton and Coll, 2005).

3.2 Aims

This research aims to probe how the concept of CT is understood by employers who engage graduates from the Bachelor of Pharmaceutical Science. It is our intention to develop a better understanding of the utility of CT in the workplace, from the employers' perspective. Specifically, this research addresses the disconnect in CT conceptualisation between the tertiary sector and the pharmaceutical and consumer goods industries within Australia. The findings may inform curricula development around CT and therefore would be specifically useful for educators and students in the pharmaceutical sciences and related fields in developing CT at an undergraduate level.

This research utilised semi-structured interviews, as detailed below. Specific companies were selected based on pre-existing relationship with the Monash Faculty of Pharmacy and Pharmaceutical Science (MPPS), either through the taking of students on work placements or as employers of MPPS graduates. All of these companies operate R&D or production facilities within the greater Melbourne area, Australia and operate in the local, national, or international markets.

This research will primarily investigate:

1. How applicable companies from these industries conceptualise CT,
2. Whether these companies expect universities to be the sole source of student CT development, and
3. The methods companies use to assess CT in graduates during the hiring process.

This paper focuses primarily on the first of the above research objectives, and will follow the investigation, starting with a qualitative analysis of the transcribed interviews and identification of key emergent themes. Next, these themes will be qualitatively analysed to determine the degree to which these themes were discussed and how that reflects their relative importance. The remaining two research aims will be considered separately through a brief qualitative discussion, highlighting key findings and any implications for curriculum design and teaching.

3.3 Study design and implementation

3.3.1 Measures

In addressing the research aims, industry representatives were invited to take part in a semi-structured interview to gauge their perspectives on CT. This method of collection was chosen to allow respondents to develop ideas freely while staying within the structure and guidance of a set of questions (Cox, 2008). The interview contained open-ended questions which looked at industry expectations of graduates and skills requirements, industry understandings of problem-solving and CT-type skills in the workplace, and industry opinion on the skills and intellectual criteria of Facione (1990) and Paul and Elder (2008).

The structured content of the interview was revised several times based on feedback from colleagues who had previously utilised interviews as a data collection method for canvassing opinions from industry. This feedback focused on removal of redundant items and a redesign of potentially leading questions. Additionally, our approach to design and piloting of the semi-structured interview questions followed that outlined by Turner (2010) for what he describes as “standardized open-ended interviews”. His outlined approach includes a deliberate choice towards open-ended questions, with neutral and clear wording.

3.3.1.1 Semi-structured Interview Questions

From the interview, it was important to clarify which graduate jobs were being discussed. The first question below acts as a clarifying question, followed by the remaining questions relevant in answering the objectives of this paper:

(i) What roles do your graduate employees typically undertake in their first year of employment? (ii) Can you explain what exactly you mean when you say critical thinking? (iii) How would you describe critical thinking, in relation to day-to-day work for a graduate in your company? What sort of problems do they have to solve? (iv) How do you evaluate or know if critical thinking skills are good/lacking for a graduate on the job? (v) Ideally, in your opinion, when should critical thinking skills be taught?

In all cases, participation was voluntary, and interviews were conducted during business hours at the workplace of the respondents. Respondents consented to being audio recorded for the purposes of the creation of a verbatim transcript. The institutional human research ethics committee, granted ethics approval for the study.

3.3.2 Participants

Interviews were conducted with 38 respondents from 21 companies. Of the respondents, 37 were technical managers or direct supervisors of graduates, and two were human resources staff. The 21 companies were classified based on their primary business (*e.g.* personal care products, analytical services) or the departments that the respondents represented within a larger company (*e.g.* research and development). In each case, no company was classified into more than on category: cosmetics/cosmeceuticals research and development (R&D) (n = 4) drugs and vitamins R&D and production (n = 4), industrial chemicals production (n = 4), personal care products (n = 3), analytical services (n = 2), food/food additives R&D/quality control (QC) (n = 3), and clinical trials (n = 1).

3.3.3 Analysis

3.3.3.1 Addressing Research Aim 1: How Companies Conceptualise CT

To address the question of how applicable companies conceptualise CT, interview transcripts were coded and analysed in order to identify potential emergent themes, which could then be grouped into categories. To this end, Questions *ii*, *iii*, and *iv* of the interview (as listed above) were analysed and categorised using the process outlined below. Originally, Question *ii* was intended to provide some case examples of CT use by graduates. However, respondents tended to provide vague or general answers rather than specific examples. As such, Question *ii* was only analysed alongside Questions *iii*, and *iv*.

Verbatim transcripts were created from each interview. Due to the free-flowing nature of the interviews, in multiple instances respondents would begin a response to one question and inadvertently respond to a following question or provide further detail to a previously asked question. This was then addressed through remapping responses to more relevant questions.

Analysis of this data was based on the "process of inductive coding" described by Thomas (2006), which involves (1) preparing the raw data, (2) close reading of the text to become familiar with general themes, (3) creation of categories, (4) allowance for overlapping coding and uncoded text, and (5) revision and refinement of the categorisation system. Steps 1 and 2 were conducted during the transcription process using standard word processing software. The transcripts were then cut into individual sentences (utterances) and imported into a spreadsheet editor for categorisation.

Initially each fragment of speech (hereon noted as *utterance*) was categorised against the CT skills of Facione (1990) (namely: *analyse*, *evaluate*, *interpret*, *conclude*, *explain*, *self-regulate*) and intellectual criteria of Paul and Elder (2008) (namely: *accuracy*, *precision*, *relevance*, *significance*, *breadth*, *depth*, *clarity*, *logic*, *fairness*). Utterances were sorted under each of these emergent categories when the content of the statement was related to the definitions provided by in the indicated literature. When sorting each utterance, it was important that the utterance could be directly attributed to the action or behaviour that a *graduate employee* would exhibit in the workplace. This excluded general commentary or, in some cases, the actions that a more experienced staff member would be expected to exhibit.

3.3.3.2 Themes validation and groupings

A secondary analysis and categorisation occurred with emergent categories. Two education-focused researchers were each randomly assigned 25% of the industry utterances and asked to determine emergent categories. Following, all utterances were then classified under those emergent categories. A further analysis of unclassified utterances was undertaken to determine if any further categories needed to be created. All final emergent categories were grouped broadly under the following headings: *actions*, *traits*, *good business-sense*, *problem-solving approach*, and *employability outcomes*. The full set of emergent categories indicates the theme name, a brief description, and an illustrative example from the transcripts (*Appendix 1. Chapter 3: Supplementary Table – Emergent Categories*, pg. 201). Categories were analysed quantitatively both at the question level and looking at overall transcripts. As some interviews involved multiple respondents from the same company, the quantitative analyses were conducted on a *per company* basis. For each question, the percentage of respondents that discussed each category at least once was calculated. In some instances, no respondents from a company discussed certain categories. In these cases, the total number of companies who discussed that category were appropriately reduced. As discussed below, from these categories, the top five most expressed categories were then selected for further consideration.

With a final set of categories determined, two industry representatives were then interviewed again to determine if our interpretation of the selected categories was a fair representative of some of the utterances made. For this process, they reviewed their own utterances that were classified under the top five categories as well as a random 10% of similarly classified utterances from other respondents. This validation exercise yielded no changes to the categories or classification.

3.3.3.3 Addressing Research Aims 2 and 3: When to Teach CT and Methods to Assess CT During Recruitment

The second research aim looks at perceptions of when to teach CT to students. Analysis of this area involves a quantitative look at the proportion of companies that desire CT to be taught either at university, in the workplace, or in both. The final research aim looks at any instances where companies discussed the assessment of CT skills during the hiring process. Due to the small number of respondents, the analysis of both these research aims are limited, however exploratory, and explicatory examples are provided.

3.4 Results and Discussion

3.4.1 CT in these workplaces

Our first concern was clarifying the types of jobs that graduates from our undergraduate pharmaceutical sciences course and the general nature of the CT skills they were expected to employ. We are aware of previous graduates from this course who were directly employed into roles that were not the primary focus of the course; for example, sales & marketing, tertiary level laboratory demonstrating, and finance. For the purpose of this research we wanted to focus on those jobs which lead directly from the course material. In practice this means a laboratory-based job in a research, analytical or quality assurance role. In addition to these typical roles, we included input from a company that conducts clinical trials as this is also a component within our course.

The responses were categorised: *QC/QA* (n = 15), *formulation/product development* (n = 11), *administrative/technology transfer* (n = 2), and *no response* (n = 2), where the counts indicate the number of companies that mentioned these work areas as being typical of a recent graduate from our course. Only three companies did not mention either *QA/QC* or *formulation/product development* as typical graduate jobs (two of these companies gave no response and the last company conducts clinical trials whose work is mainly administrative).

3.4.2 Defining and understanding CT

For ease of use five of the top categories were selected for further consideration. To this end, the researchers selected the top five categories as listed below. In selecting these categories, only those categories which had at least two-thirds of the companies (*i.e.* n ≥ 15) discussing these categories. Further, in the researchers' opinion represent a manageable number of distinct areas that higher education teachers and designers could utilise in curricula development. The top five emergent categories of CT conceptions are listed in Table 3-1 including the percentage of companies that were recorded as having at least one utterance in the listed categories. The full list of emergent categories can be found in *Appendix 1. Chapter 3: Supplementary Table – Emergent Categories*, pg. 201.

Table 3-1. Identified categories, definition, and percentage response to industry questions around defining and understanding CT in their company context.

Category	Definition	Responding Companies
Systematicity	A disciplined, orderly approach to the problem-solving process.	100 %
Business-sense	An awareness of the constraints of working within the business context, in relation to time, resources, *etc*.	86.4 %
Multiple solutions	Providing multiple viable recommendations/solutions.	72.7 %
Consideration of implications	An awareness and understanding of the effects of one's decision or recommendations.	68.2 %
Identification/ Awareness	To identify issues or problems and determine their component parts, and to identify the conceptual relationships of those parts to each other and to the whole.	68.2 %

Although respondents identified the aforementioned emergent categories as being representative of CT, to ensure that they in fact representative they must be compared against accepted definitions of CT. Three such definitions are, Halpern's (1998) definition of CT being a 'purposeful, reasoned, goal-directed' act, Ennis' (1993) understanding of CT as 'reasonable and reflective thinking', and Facione's (1990) conception of CT being 'purposeful, self-regulatory judgment'. Identified categories are compared against descriptions given in each of the three sources listed above. Table 3-2indicates how the identified categories match these criteria.

These categories definitely do not cover the entire gamut of CT as defined in the above three publications. However, this is not the intent of this research and it is only required that each category 'fits' within the provided definitions of CT, and so are themselves examples of CT. One standout exception that is not captured in the above industry-aligned CT concepts is the notion of *self-reflection* or *self-regulation* that appears in various guises in all three of the listed publications. While this idea of self-reflection was not raised in the industry interviews, it may be worthwhile later considering how it can be incorporated within those five tabulated industry-aligned CT concepts.

Table 3-2. Comparing emergent categories with published understandings of the nature of CT

Category	**Halpern (1998)**	**Ennis (1993)**	**Facione (1990)**
Systematicity	“habitual use of plans”, “willingness to abandon non-productive strategies”	“plan experiments …”	“orderliness in working with complexity”
Business-sense	“an awareness of the social realities that need to be overcome”	“define terms in a way appropriate for the context”	“to assess the contextual relevance of … information, principles …”
Multiple solutions	“generating and selecting alternatives and judging among them”	“conceiving of alternatives”	“formulate multiple alternatives for resolving a problem”
Consideration of implications	“evaluating the outcomes of their thought processes—how good a decision is or how well a problem is solved”	“draw conclusions when warranted, but with caution”	“educe the consequences …”
Identification/ Awareness	No clear mention	“identify conclusions, reasons, and assumptions”	“recognize a problem and define its character …”

More interestingly, the pre-existing concepts posited by Facione (CT actions), and Paul and Elder (CT criteria) were not addressed as extensively as these emergent categories. Specifically, when queried about the nature of CT (interview questions 3.1 and 3.2; *“Are these [CT] skills important in your company?”* and *“Can you explain what exactly you mean when you say [CT]?”*), the most discussed pre-existing CT concept was *conclude* (40.9%, n = 9) (present in Facione, 1990). The highest CT criteria were *breadth* and *depth* (both 36.4%, n = 8) (present in Paul and Elder, 2008). Comparatively more companies discussed *systematicity* (81.8%, n = 18) and *business-sense* (63.6%, n = 14). These appear to suggest a focus on CT as a means to solving specific, business-related problems. Pertinently, they appear to recognise problem-solving as being within the context of the business setting, rather than loftier goals such as being of benefit to wider society as per Facione’s (1990) definition of CT as those “CT skills …, which are the basis of a rational and democratic society”. This would appear to be a more holistic approach to CT than that espoused in the CT literature.

A similar study was recently undertaken in the field of chemistry (Danczak *et al*., 2017). In the initial part of this research, employers were contacted online to answer the question: “What does the term ‘Critical Thinking’ mean to you?” In those findings, *problem-solving* and *identification of opportunities/problems* were the top two categories of responses from employers (over 44%, 35% respectively). Danczak *et al*. describe *problem-solving* broadly as a "problem and/or something that needs to be resolved". This orientation of CT towards problem-solving is also evident in our research, where many of the top themes when defining CT also related specifically to the solving of a problem or issue (*systematicity*, *multiple solutions*, and *considering implications*, for example). Similarly, the *identification of opportunities/problems* as identified by Danczak *et al*. may be reflected in the categories we found; *consider implications*, and *identify*. There is resonance between the findings of Danczak *et al*. and this research in that problem-solving (and CT) in industry appears to focus more on the product of the problem-solving and less on the procedures or conceptualisations of CT as posed by Facione, Ennis, and others. In these industries then, CT is understood more as a problem-solving tool. Responding companies from a range of industries identified CT as being a systematic process, solving problems in the business context, identifying problems and required information, providing multiple potential solutions, and being aware of the consequences and implications of those solutions. These responses are interestingly comparable to those found by Papadopoulos (2010) when looking at business graduates within the same geographical area that our study was conducted. In that research he found that while the technical skills are important, it was incumbent on students to "take a more holistic approach to education, in which co-curricular and personal life experiences are as important as coursework".

3.4.3 When to teach CT and implications for higher education curricula

Responses were qualitatively analysed to determine whether industry representatives felt that CT should be developed at university or on-the-job and how this may influence the perceived employability of graduates. From the responses, 95.5% (n = 21) of companies indicated that CT should be developed at the university-level, with a smaller amount discussing development of CT in the workplace (77.3%, n = 17), with most of these companies discussing the development of CT both at university and in the workplace. A much smaller number of companies that discussed teaching of CT exclusively at either university (22.7%, n = 5) or in the workplace (4.5%, n = 1). Explicatory responses are given below.

In discussing CT during the hiring process, most respondents discussed generally how they utilise behavioural-style questions (81.0%, n = 17) that may or may not elicit a response around CT. Many companies (61.9%, n = 13) were also quick to indicate that work experience, or other prior experience is highly regarded during the hiring process. However, these responses were not directly addressing or discussion CT skills.

The general consensus among respondents was that CT should be first taught at university and then refined in the workplace. The following respondent quote exemplifies this position:

> *"It would be good to have some basic critical thinking abilities before you enter the workplace but I do find that the experience [sic] that you get in the workplace do add on to critical thinking."*

This quote is also indicative of the overlap of discussion around teaching of CT at university but also development within the workplace. Several respondents further discussed specifically how CT could be taught at university by way of providing an initial understanding, or a common language. Then workplaces could develop this understanding further, within their own context. Interestingly this viewpoint does reflect the literature discussions around generalisable CT skills and context-specific CT skills development. What was regrettably not discussed in this instance was whether a teaching model similar to Ennis' mixed approach to teaching CT would perhaps address the generalizable skills and context-specific skills both while the student is within the university system.

Several respondents discussed how CT might best be taught, with some opining that CT should be taught within a pre-existing unit of study, in the context of their studies:

> *"I wouldn't teach it separately, it would be too fake, it wouldn't be real enough … Don't teach it specifically, just teach it within the curriculum."*

> *"I think you can still be clear with the outcome [of a laboratory practical] and what resources you can put towards it but you can tell them less about how they should go about it and let them develop that."*

Following the observation that CT should be developed at university and then refined in the workplace, there are some clear implications for higher education providers and curricula designers. Holmes, Weiman, and Bonn (2015) argue for the development of CT skills in a scaffolded manner across general sciences education as a way to address a perceived lack of opportunities to develop these skills. Specifically, they argue for explicit CT education that requires students to both learn and actively apply CT skills in their context. Interestingly this aligns with the view of Lund (1997) around the use of well-developed authentic assessments to induce higher order thinking. Holmes, Weiman, and Bonn (2015) allude to the notion of scaffolding this skills development along the undergraduate course. If other degree discipline areas were to use a similar approach to understanding their relevant industries' skill requirements, they would necessarily need to engage with those industries. The additional benefit here is the breaking down of obstacles between tertiary institutions and industry. Looking specifically at the pharmaceutical industry, Paranhos and Hasenclever (2011) noted that a major obstacle to further university-industry relationships is "mistrust, distance and a lack of understanding between researchers and companies." True engagement that can then be seen to be acted upon is another clear way to develop that trust and understanding.

3.4.4 Effects on employability

Following this line of reasoning it is not surprising then that some companies also considered the effect that poor CT ability may have on graduate employability:

> *"If you don't have the critical thinking part, at least the basics of it introduced at university you might be at the risk of not getting a job."*

> *"Maybe then I don't select them if they don't have a particularly strong critical thinking / problem solving approach."*

Extending this understanding of the development of CT in students, it became clear that CT is seen as a very desirable skill for a student to possess when they transition to industry. What was not yet clear though was how companies might then assess this skill during the recruitment process. It was then pertinent to understand whether the CT development might lead to an improvement of the likelihood of students becoming employed.

While much discussion on the assessment of skills during the recruitment process was non-specific to CT, some observations emerged around assessing student CT ability through behavioural-style questions.

For example;

> *"Either we ask for case studies where they used different thinking or some life experience where they had to come across some solution that was not mentioned in books."*
>
> *"'Give me an example of a project that you had control over.' And then we talk through bits like 'what happened when it went wrong?'"*

This lack of directed questioning on CT (or problem-solving, as many respondents preferred to discuss) may be an expectation or understanding that students do not have industry-based examples to draw on:

> *"Again we appreciate that they may not have all the … Some of the questions around experience and they may not have the work experience yet …"*

However, some respondents discussed the use of CT skills from different (non-industry) contexts:

> *"From a personal perspective when I have interviewed people … it is tricky because sometimes students don't have the experience about 'have had any experience where you had a problem and what have you done to solve it?' Sometimes it could be in a retail environment."*
>
> *"Some will think up good examples, and again this can be coming from their other activities."*

What was understood from analysis of this section was that companies clearly articulated the desire for universities to further undertake the teaching and development of CT skills. This is curiously coupled with the notion that these skills are not directly, explicitly assessed during the recruitment process, even though it is indirectly probed through behavioural-style questions looking at examples of how students have handled problems they encountered. While use of CT to solve industry problems was seen as the ideal (most direct) expression of CT skill, companies were aware that recent graduates may not have these experiences and can sufficiently rely on other examples to demonstrate the same skills. This may indicate an area for students to be proactive in highlighting how they have demonstrated these CT skills. Whether this takes the form of real-world demonstration of these skills or hypothetical demonstration of these skills (through an above-average score on a CT test for example) was not considered here. What does become apparent is the desire for graduate applicants to be aware and to be able to talk about these skills:

"If students come into an interview and talk about these things, they will make everyone's ears prick up and think 'that's exactly what we need.' Because our pain lays in this space."

For the student, the benefits of developing demonstrable and transferable CT skills are clear. Being able to take the skills development from university and express it either in a placement or during a job interview will increase one's chances of becoming employed. Nevertheless, the ability to develop and practice these CT skills are predicated on the higher education curriculum designers and teachers providing sufficient and appropriate opportunities to do so.

3.5 Study limitations and future research

This study represents an initial investigation into how CT is conceptualised by industries relevant to the employment of graduate of the pharmaceutical sciences. We recognise the need for further study in this area which could address some of the limitations of this research. Some future directions may be grouped as: (i) wider sampling, (ii) the implications for teaching CT at a university level but at different stages in a degree, and (iii) the specific modes of assessing CT skills within the hiring process or the ways in which CT is implicit within other workplace performance indicators.

A larger sample of respondents from a more geographically diverse background would allow for a closer statistical analysis of emergent themes. This would enable discovery of differences in conceptualisation based on location, company size, and sub-industry type (*e.g.* fast-moving consumer goods compared to pharmaceutics). Additionally, a wider sample would allow for analysis of those graduate jobs that are not the main focus of the course (such as sales & marketing). To provide a richer dataset, case studies from employers can be sourced that look specifically at how the identified categories are being utilised on a day-to-day basis by graduates.

Of interest to university educators, further research should consider the number and type of respondents who felt CT being taught at university should be taught as a separate subject, only taught within final-year studies, or taught within an industry context utilising real-world examples.

In understanding how CT is assessed in the hiring process, further analysis could investigate: (i) which of the industry-aligned CT concepts are most obviously being assessed using the behavioural-style questions, and whether this may imply a greater importance being placed on any particular industry-aligned concept, and (ii) if industry-aligned CT concepts are being assessed during the hiring process, are they also the same CT concepts that are highlighted in the understanding of CT in day-to-day activities. We believe that these further analyses do not detract from the other findings as already presented herein.

3.6 Conclusions

This research suggests that those industries hiring our graduates either require a more holistic approach to CT, in that they are goal-oriented and contextually dependent in their CT use for problem solving. However, alignment of emergent CT categories with CT definitions espoused by adherents of generalizable CT does lend credence to the notion of generalisable industry-aligned CT skills. Furthermore, the emergent categories do not appear to be contextually limited to those companies or industries interviewed in this study. Alternatively, it may be that they interpret CT in a more unidimensional manner than the approaches favoured by Facione, and Paul and Elder (*i.e. systematic problem solving*, rather than *analysis*, *depth*, *breadth*, *logic*, *etc*.). This may indicate a need for greater, and/or more explicit, development of industry-aligned CT skills in our students. Following from respondents' perspectives on teaching CT and CT in the hiring process, a greater explicit development of the awareness and use of these skills may have positive employability outcomes.

Postface

The findings from this study form the conceptual basis of the rest of the dissertation. The five industry-aligned metrics of CT (*being systematic*, *having strong business-sense*, *considering multiple-solutions*, *considering implications*, and *identifying problems and potential solutions*) will be revisited in the second section of the dissertation. In the next chapter we take a slight deviation to further investigate how industry uses CT terms.

Chapter 4

Critical Thinking in Job Advertisements

Preface

Now knowing how industry conceptualises critical thinking (CT) in their context, let us take a brief look at whether industry is explicitly looking for CT when recruiting students from our degree. This chapter covers a year-long study into the language use in job advertisements. In particular we are looking for the frequency of use of CT words. We look for a range of CT words and higher-order thinking words to determine the extent of usage in relevant job advertisements. This process used author-generated computer code, which is provided as reference in Appendices 10.3 – 10.7, in the end matter of the dissertation. The full dataset can be accessed via the published version of this manuscript.

Chapter Contents

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Let's talk business: The language recruiters use to attract STEMM graduates.

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Abstract

The last decade has seen a shrinking of degree-level employment opportunities for young people (aged under 24 years) in Australia and globally. This research aims to better understand the job advertisements to which our graduates are exposed. This paper presents a universal method to collect and process advertisements from an online job board. Two million job advertisements were extracted, cleaned, processed and reviewed to highlight the uses of Bloom's Taxonomy (*evaluate* and *create* levels) and critical thinking (CT) words within. This study looked at those advertisements of interest to graduates from the Bachelor of Pharmaceutical Science in Australia. Analyses indicate that use of these words are not dependent on the size of the company, the salary of the advertised position, job permanency, nor specific industry. However, Bloom's Taxonomy words were used to a much greater extent than CT words potentially reflecting the lack of clear and coherent definition and conceptualisation of CT skills in industry. We

encourage increased collaboration and discussion between institutions and industry to define and articulate the skills graduates require.

4.1 Introduction

Following the global financial crisis (GFC) in 2008-09, the workforce participation rate for young people (aged 15 – 24 years) decreased significantly in many countries (Skattebol, Hill, Griffiths, & Wong, 2015; Junankar, 2015). Employment data from the OECD shows that youth unemployment (as a percentage of total youth labour force) has been slowly returning to pre-GFC levels since peaking in 2010 (OECD, 2018). Canada and the US both show signs of youth employment returning to pre-GFC levels yet (DePillis, 2018; Janzen, 2018). In a curious contrast, the Australian employment market continued to see youth unemployment increasing until 2014-15, with levels only now starting to decline (Australian Bureau of Statistics, 2019a). Australian university graduates are facing challenging conditions as job seekers. The period 2008-16 saw a contraction in youth jobs with an expansion of jobs for older Australians (Australian Bureau of Statistics, 2019b,c). The changes to graduate employment over the past decade in Australia was not homogenous across disciplines. A 2018 report by the independent Grattan Institute noted that following the decline in graduate employment for the decade ending 2014, graduates from health-related degrees are more likely to be employed within four months of graduation compared to generalist science and arts degrees (Norton & Cherastidtham, 2016). Between 2006 and 2016 the overall labour force participation rate for all bachelor's degree holders aged 25 to 34 stayed approximately constant, while those for the sciences and creative arts decreased by 5-10% (Norton & Cherastidtham, 2016). This data points to a difficult job-seeking environment for current graduates, especially in the sciences.

Since the turn of the century, the Australian job seeker market has seen dramatic shifts in the way jobs are advertised. Advertisements have largely shifted from traditional print media to online sources (Jepsen, Knox-Haly, & Townsend, 2014, p. 10), typically company websites or online job boards (Graduate Careers Australia, 2013). Australian online job boards (*e.g.* JobSearch, CareerOne, Seek, and Jora) act like the classified sections of newspapers by bringing together a wide range of domestic and international advertisements. Australian universities are actively encouraging students to utilise these job boards as part of wider job seeking strategies (for example, The University of Melbourne (*n.d.*-a)).

Looking specifically at chemistry, life sciences, and laboratory sciences industries, the Australian government has forecast jobs growth of 6% over the next five years (Department of Jobs and Small Business, 2019). This growth in jobs goes some way to ameliorate job shortages noted in these areas (Jepsen *et al*., 2014, p. 30) but high volume of job applications from graduates for these positions (Jepsen *et al*., 2014, p. 38). Research into how these challenges affect job advertising to graduates is lacking. With further research into this area, universities and job-readiness services would be able to better prepare graduates for the job application process.

Looking at the process of job application, Harold, Uggerslev, and Kraichy (2013) outline a series of three cognitive steps that prospective job applicants undertake in the process leading up to accepting a job offer. These steps are; *Application Decision* '(Do I apply?'), *Withdrawal* ('Do I continue, or withdraw?'), and *Job Acceptance* ('Do I accept?'). In the context of our research, we are interested in the first step; overcoming the barrier to applying. In this first step, potential applicants are undertaking self-screening (Ryan, Horvath, & Kriska, 2005; Ryan, Sacco, McFarland, & Kriska, 2000). This screening includes a self-judgement on how likely they are to get the job. One aspect of perceived success is how well they fit the requested skills. In a study conducted on US firefighters, (Ryan *et al*., 2005) investigated the link between advertisement informativeness and applicant self-selection. In their study, informativeness was defined as the level of "accuracy and detail of information provided about the job" (Ryan *et al*., 2005, p. 239). Their findings suggested that a greater level of informativeness may have led to applicants being able to screen themselves out of the process potentially due to poor perceived job fit. It stands to reason, perhaps uncontroversially, that a more detailed and accurate job advertisement benefits the company (through reduced inappropriate applicants) and potential applicants (through reduced effort applying for inappropriate jobs).

The question then returns to assessing the quality of job advertisements. Ryan *et al*. (2005) outline one method in which they took a subjective measure of the informativeness of twelve job sources by having three recruiters rate the quality of advertisements on a five-point scale. This method would not be feasible in this research due to fundamental differences in the industries being investigated. In our context, graduates from our Bachelor of Pharmaceutical Science course typically enter a much broader range of companies and industries. A larger number of companies leads to a vastly increased number of job advertisements. Instead we choose to look at the types of words that job advertisers are using. In particular, we are interested in the recruiters' lexical choices and what they tell us about the jobs being advertised.

For the purposes of this research, we consider the informativeness of advertisements in terms of companies clearly articulating the skills and behaviours desired in graduates. We look specifically at higher-order thinking skills, namely critical thinking (CT) skills. In this way we consider the level of detail of the job advertisements. For example, compare two hypothetical advertisements. One requires the applicant to be able 'to apply and understand the principles of Good Laboratory/Documentation Practices in day-to-day work'. Under Bloom's Revised Taxonomy, the actions *apply* and *understand* represent lower-order thinking (Anderson & Krathwohl, 2001). Compare this with the need to be able to 'evaluate Good Laboratory/Documentation Practices in day-to-day work'. In this instance, *evaluate* indicates the need to critically reflect on the quality of those *Practices* in their daily context which, in itself, has built on an understanding and application of those *Practices*. In this way, the use of higher-order Bloom's Taxonomy wording and CT phrases, companies are explicitly elucidating the degree of skill expected of graduates.

As Biggs and Tang (2011) note, the verb choice is indicative of importance ascribed and required level of understanding needed. We also wanted to investigate the degree of problem-solving and CT skills being requested by employers, both from a traditional CT literature approach and from an industry-aligned CT approach. While job advertisements are not part of the education domain to which Bloom's Revised Taxonomy is usually applied, there appears to be no reason why we cannot utilise the taxonomy to investigate whether the job advertisements represent the same level of sophistication that educators instil in their students.

Through understanding the skills requirement of industry, we as educators can better inculcate these skills and behaviours in the minds of our students. This is an ongoing process globally that has taken a variety of approaches to gauging industry requirements, including case studies leading to experiential engineering courses (Arlett, Lamb, Dales, Willis, & Hurdle, 2010), questionnaires investigating specific soft skills in science students and employers (Gray, Emerson, & MacKay, 2005), and targeted interviews with employers in smaller courses (Pearl, Rayner, Larson, & Orlando, 2018). These approaches capture broad skills and behaviours but do not consider the specific wording or phrasing that graduates will encounter through the job application process. It is imperative to identify and adapt industry understanding of these skills to allow for a closer alignment of employer expectations and educator instruction (Penkauskienė, Railienė, & Cruz, 2019, p. 811). In short, this leads to a better matching of what employers say they want, and how and what we teach. What then can the verb choice made in job advertisements tell us about these skills that our graduates are being asked to demonstrate to potential employers?

4.2 Aims

This study investigates the use of words from Bloom's Revised Taxonomy and CT (CT) within science, technology, engineering, mathematics, and medicine (STEMM) job advertisements suited for graduates of the Bachelor of Pharmaceutical Science (BPharmSc) in an Australian context. We will consider the following research questions:

1. Whether there are links between word category usage across industries, and
2. Whether there are links between word category usage and size of company, offered salary, and permanency.

4.3 Method

4.3.1 Linguistic analysis using a word count strategy

In this research we will be utilising a word count strategy to analyse job advertisements. Ultimately this is a correlational study comparing the usage of particular Bloom's Revised Taxonomy and CT words across different industries and job types. Using a word count strategy is a crude method of linguistic analysis as it does not distinguish context or multiple meanings of words. A review of the contextualisation of the words is in part completed through review by the principal investigator. Additionally, we can think of a word count strategy as a probabilistic method of analysis. If our analysis were to find that a grouping of advertisements tended to use a variety of words from a particular cognitive domain of Bloom's Revised Taxonomy, then we may be more confident in our conclusions drawn around word usage. For large datasets, and large job advertisements, the errors associated with word count analysis are reduced (Newman et al., 2008). Other refined strategies of linguistic analysis include the Linguistic Inquiry and Word Count (LIWC) (Tausczik & Pennebaker, 2010) which aims to categorise word usage based on subjective attributes, such as positivity and negativity. Similar to our approach, the LIWC is a probabilistic approach to analysis which cannot distinguish between language uses such as irony, sarcasm or idioms. However, in our analysis we rely on a homogenous data source that is likely free from irony, sarcasm and idioms.

4.3.2 Collection of advertisements

The job advertisements were collected from a major Australia-based online job board between July 2016 and June 2017. This job board was chosen as it contained easily accessible advertisements, the then largest pool of job advertisements available, and is one of the longest running online job boards in Australia. This initial data collection found nearly two million job advertisements posted during this period. In each case, a copy of the original job advertisement was downloaded using a free software solution (Roche, 2017).

4.3.3 Extraction of details and text

The downloaded job advertisements underwent preliminary data cleaning to remove extraneous webpage coding and formatting. Due to the template style of the original advertisements, each advertisement had its specific details and its core advertisement text extracted. These details included the industry, advertising company, job title, and salary range. The specific details were entered into a database for further analysis while the advertisement text was retained with an identifier linking the text back to its particulars. This process was conducted electronically using bespoke code written using Visual Studio 2017 (Microsoft, Washington).

4.3.4 Selection of degree-appropriate advertisements

For the purposes of our research, we were interested in analysing only those job advertisements that would be suitable for a new graduate from the Bachelor of Pharmaceutical Sciences degree. Specifically, we wanted only those jobs that satisfied four criteria: (i) located in Australia, (ii) non-casual positions, (iii) in specific industries that our degree caters for, and (iv) of specific job type/title that our degree caters for.

4.3.4.1 Rationale

Our course aims to prepare students primarily for the domestic market with the intention that they become employed on a full-time or near full-time basis. Generally, pharmaceutical sciences courses aim to develop skills that are appropriate for work in specific industries, particularly pharmaceutical development and consumer goods development (Monash University, *n.d.*-b; RMIT University, 2019; The University of Adelaide, 2019; University of Canberra, 2019; University of South Australia, 2019). The skills that are taught to students could be used in a much wider variety of jobs (for example, sales or managerial assistance), however these are neither the focus of the course nor of this research.

4.3.4.2 Selection results

In determining the specific industries and job types to further analyse in this research, we considered the jobs promoted by pharmaceutical sciences degrees, and known companies and industries in which our alumni were employed directly from university. The selection of relevant job advertisements follows a two-step process: (i) *Consider only appropriate industries*, and (ii) *Consider only appropriate job titles*.

The advertisements are classified according to a discrete list of industries. This allowed the industry list to be evaluated independently by two research team members who have direct experience and oversight of the course student placement program. This process allowed for the removal of clearly erroneous industries such as ‘agriculture/farming’ and ‘accountancy’. Where there was disagreement between the two team members, this was resolved through discussion or retained if no resolution could be made. Applying criteria (i) – (iii) resulting in approximately 120,000 job advertisements, from the initial two million.

The remaining jobs were then again evaluated by looking at the job title to assess whether they were still appropriate for further consideration. While we had now selected job advertisements that fell into the appropriate industries, this final criterion ensured the advertisements were correctly classified and appropriate for our students. For example, it is possible that graduates of our course could work in the public sector which would be classified as the ‘government’ industry. However, under this industry are positions with the armed forces, including ‘Doctor (Medical Officer)’ which are not appropriate for our graduates. Additionally, although potentially not stated in the job advertisements, we judged that our graduates will not enter industry at the level of a 'senior', 'manager', or 'CEO' and so these were also removed. This final evaluation of advertisements was completed independently by the same two research members and also by a member of the faculty alumni engagement office. Where any disagreement occurred, this was resolved through discussion or retained. This final evaluation gave a final list of 2,107 job advertisements that met all four criteria.

4.3.5 Categories of word choices – Bloom's Revised Taxonomy and critical thinking

We accessed multiple sources to arrive at a broad list of Bloom's Revised Taxonomy synonyms and concepts, although these were primarily adapted from Anderson and Krathwohl (2001) and Biggs and Tang (2011). For this research we were only interested in words that sit within the 'evaluate' and 'create' levels of the cognitive domain, as indicated by Anderson and Krathwohl (2001). The CT domain words were sourced from the theories of Facione (1990) and Paul and Elder (2008). As we were conducting this research in an Australian context, we supplemented these CT words with the industry-aligned CT metrics outlined by Pearl *et al*. (2018). This left us with six categories; (i) Bloom's Revised Taxonomy 'evaluate', (ii) Bloom's Revised Taxonomy 'create', (iii) CT explicit indicators, (iv) Facione's CT actions, (v) Paul and Elder's CT standards, and (vi) Pearl *et al*.'s CT metrics.

Each word was considered in multiple forms to ensure that we captured its every possible use. The words were converted into *verb-form* (first-, second-, and third-person in present tense, simple past tense, past perfect tense, and gerund form), *noun-form*, and *adverb-form*. Duplicate cases were ignored (*e.g.* identical first-person and second-person forms), some adverb forms were ignored if they did not exist or refer to different lexical concepts (*e.g.* the infinitive '*to complete*' and equivalent adverb '*completely*' are different concepts). No words existed under two or more categories. A full list of the base words can be found in *Appendix 1. Chapter 3: Supplementary Table – Emergent Categories*, pg. 201.

4.3.6 Highlight and review of words

Once the word list was finalised, it was necessary to ensure that the job advertisements were using these words only as anticipated. An initial analysis demonstrated that the job advertisements typically contained a section of text discussing the potential employee and other sections discussing the company and its values. For our research we were only interested in the sections that looked at the expected behaviour, traits, and duties of the employee. Unfortunately, many of the words of interest occurred in both appropriate and inappropriate sections of the job advertisement.

Consequently, each word we were considering was highlighted in the job advertisement text to facilitate later manual review. This process was conducted electronically using bespoke coding. The text of each advertisement was then reviewed by the principal investigator to ensure that the highlighted words were being used in the context of the employee's behaviour, traits, or duties. Inappropriate instances were removed.

Through this process, we discovered 65 advertisements that contained no text whatsoever. The original copies of these advertisements were reviewed and found to genuinely contain no text and were removed from the dataset. The left 2,042 job advertisements underwent final analysis. Of these advertisements, 544 were posted by known recruitment agencies on behalf of other companies. While graduates would be applying for these jobs, recruitment agency postings are outside the scope of this research as we wish to only investigate how relevant companies directly advertise to graduates. We expect that recruitment agencies are informed about the job particulars but craft the bulk of the text themselves. This extra drafting step by a company outside the industries of interest may introduce unintended bias in word usage. As such, the remaining 1,498 cleaned advertisements were processed and had each instance of the desired words counted and reported.

4.3.7 Company details

Data on each company was collected and analysed for correlations with the Bloom's Taxonomy and CT words. We utilised the Mint Global tool provided by Bureau van Dijk (Bureau van Dijk, 2019) which is part of the Moody's Analytics group. For each company within our advertisement dataset, we collected their most-recent operating revenue as a proxy for the size of the company. These data range from 2016–2018. As we only considered Australian jobs, only Australian or New Zealand subsidiary company data was collected rather than the U.S. or European parent company, where required.

4.3.8 A note on advertisement vs position description

Ideally any analysis of the roles and responsibilities of a job would investigate that job's position description, however this research adopts an alternate approach. From the outset we acknowledge that a job advertisement may not present the whole picture of that position's intended duties and required skills. We believe that a position description or a job description would provide a fuller account. Nevertheless, we analysed only the advertisement text as these texts are more abundant, easily accessible, and of the original 2,042 advertisements, only 25 (1.2%) contained any mention of *position/job description*, *role statement*, or *more/further information*. While proactive applicants would approach a company, the remaining advertisements also had no direct contact information. Additionally, these advertisements are the applicants' first impression of the job, and they therefore inform applicants' thinking around the *application decision* ('Do I apply for the job?'), as suggested by Harold *et al*. (2013).

We are also aware that industry-specific job boards and company job boards provide a more tailored set of job advertisements (Jattuso & Sinar, 2003) than general job boards. However, our industries of interest have no such job boards in Australia, leading graduate applicants to fall-back on generalist online job boards or direct company contact. Furthermore, company job boards are very limited in the breadth of opportunities for graduates and we have identified that most large companies in our context tend to cross-post on their own job boards and generalist online job boards.

4.4 Analysis and findings

Below we present the findings of the analyses with discussion of the implications of these findings to follow in the subsequent section. The variables used in our correlational studies are presented in Table 4-1. These 1,498 advertisements are the non-recruitment agency texts only. Statistical analyses were conducted using IBM SPSS Statistics 24 (SPSS Inc., Chicago, IL).

Table 4-1. Advertisement characteristics (n = 1,498) indicating means and standard deviations of word category usage per advertisement

Word Category	**M**	**S.D.**
Bloom's Taxonomy – 'create'	4.52	3.04
Bloom's – 'evaluate'	0.79	0.96
CT explicit indicators	0.16	0.39
CT actions	1.29	1.22
CT standards	0.85	1.03
CT metrics	0.46	0.71
Advertisement Specifics	**M**	**S.D.**
Company operating revenue ($USD M)	1,025.63	3,572.18
Avg. job salary ($AUD p.a.) *	74,932	19,181
Advertisement Categories	**n**	**%**
Industry		
Manufacturing, transport, logistics	297	19.8
Medical services	401	26.8
Public service (incl. defence force)	31	2.1
Science & technology	692	46.2
Training & education services	62	4.1
Other	15	1.0
Permanency		
Full-time	1157	77.2
Part-time	119	7.9
Contact/Temporary	222	14.8

* Average job salary is the median of the advertised salary range.

4.4.1 Those who use these words use them extensively

In investigating the number of unique words used in advertisements, we calculated the Pearson product-moment correlation coefficients between each word category (Bloom's Taxonomy – create, Bloom's taxonomy – evaluate, CT explicit indicators, CT actions, CT standards, and CT metrics) to investigate category-category usage correlations. All category-category correlations were positive and significant at the $p < 0.01$ level ($n = 1498$), except for 'explicit indicators-standards' and 'explicit indicators-actions'. That is to say that generally the increased use of one category of words is associated with increased use of each other category of words. These correlations were strongest with 'Bloom's Taxonomy – create' with all exceeding the $r = .30$ threshold for moderate correlation strength suggested by Cohen (1988), except for correlation with CT metrics of Pearl *et al*. (2018) (see Chapter 3) which is a weaker correlation.

Table 4-2. Pearson product-moment correlations between word categories.

Measure	1	2	3	4	5	6
1. Bloom's – 'create'	–					
2. Bloom's – 'evaluate'	.358*	–				
3. CT explicit indicators	.185*	.030	–			
4. CT actions	.338*	.337*	.031	–		
5. CT standards	.336*	.232*	.068*	.185*	–	
6. CT metrics	.208*	.145*	.074*	.169*	.095*	–

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

4.4.2 Salary and company size are poor indicators of word usage

Job salaries, which were provided in a small number of advertisements (n = 254, 17.0%), ranged from AUD$34,902 p.a. to AUD$130,000 (mean = $74,932, S.D. = $19,181). For these advertisements, the average salary was calculated and correlated against unique word usage in each word category. Significant negative correlations were found between average salary and CT explicit indicators ($r = –.174$, $p < .001$) and CT metrics ($r = –.133$, $p < 0.01$).

A larger number of company details could be found using Bureau van Dijk (2019). Matching these details to the job advertisements gave a significant number of advertisements with associated company operating revenue (as a proxy for company size) (n = 797 advertisements with matched operating revenue data, 53.2% of all non-recruitment agency advertisements). For this correlation it was important to ignore advertisements submitted by recruitment agencies on behalf of other companies which were never named within the advertisement text. The 2016–2018 operating revenue of each company was correlated against unique word usage in each word category. Operating revenues ranged from USD$243,000 to USD$47B (mean = $1.02B, S.D. = $3.6B). There were no correlations between operating revenue and word category usage that were significant at the $p < 0.05$ level. Even by limiting the analysis to smaller companies (operating revenue sub-USD$1B, n = 643, 42.9%) only the explicit CT definitions was correlated ($r = -.110$, $p < 0.01$) with operating revenue indicating a small negative relationship as per Cohen (1988).

4.4.3 No clear associations between permanency, industry and word usage

To measure the potential effects of industry and job permanency on word category usage, separate one-way ANOVAs were conducted. In both ANOVAs the word categories were the dependant variable and the independent variable was either the industry to which the job related, or the job permanency of the advertised job. By collecting the full set of job advertisements, we avoided any selection bias. Additionally, due to the large sample size, we assumed to have an approximately normally distributed number of word category usages across the advertisements, as suggested by Pallant (2016). Data was screened using Levene's test of homogeneity of variance, as suggested by Pallant (2016). Those categories which did not pass this test were subjected to Welch's one-way ANOVA. In all cases, effect size is calculated using ω^2 (omega-squared) as is comparable to η^2 (eta-squared) measure but is more appropriate for Welch's ANOVA (Carroll & Nordholm, 1975). For ease of comparison, all effect sizes were calculated using ω^2.

The results of the one-way ANOVA / one-way Welch's ANOVA associating word category usage with industry is presented in Table 4-3. All word categories, except Bloom's 'create' and CT standards, had statistically significant associations with industry at the $p < 0.01$ significance level indicating a significant association between these word categories and industry. However, the effect sizes were negligible with industry having only a small effect ($\omega^2 = 0.02$) on the association with explicit CT indicators. Associations between permanency and word category usage yielded no statistically important results. Bloom's 'create', CT indicators, and CT actions were statistically significant at the $p < 0.05$ level, but no effect size exceeded $\omega^2 = 0.01$. This indicates negligible associations with job permanency. These findings suggest that regardless of industry, and regardless of job permanency there is no strong differences in word category usage.

Table 4-3. Means, standard deviations, and one-way ANOVAs/Welch's ANOVAs for the effects of industry on use of word categories

	1	2	3	4	5			
Variable	***M ± SD***	***M ± SD***	***M ± SD***	***M ± SD***	***M ± SD***	***F***	***p***	ω^2 †
Bloom's – 'create'	4.77 ± 2.81	4.31 ± 2.96	4.00 ± 2.25	4.54 ± 3.08	4.58 ± 4.12	$F(4, 1478) = 1.23$	.298	.00
Bloom's – 'evaluate'	0.70 ± 0.92	0.90 ± 1.14	1.16 ± 0.86	0.74 ± 0.87	1.00 ± 0.70	$F(4, 160) = 4.92$*	.001	.01
CT explicit indicators	0.19 ± 0.42	0.08 ± 0.28	0.13 ± 0.34	0.21 ± 0.44	0.08 ± 0.27	$F(4, 160) = 9.33$*	< .001	.02
CT actions	1.25 ± 1.28	1.37 ± 1.24	1.84 ± 1.16	1.20 ± 1.18	1.56 ± 1.07	$F(4, 1478) = 3.84$	< .001	.01
CT standards	0.78 ± 0.91	0.90 ± 1.02	0.77 ± 0.92	0.79 ± 0.92	1.48 ± 2.14	$F(4, 154) = 2.45$*	.049	.00
CT metrics	0.34 ± 0.56	0.49 ± 0.73	0.81 ± 1.01	0.49 ± 0.74	0.29 ± 0.52	$F(4, 158) = 5.83$*	< .001	.01

(1) manufacturing, transport, logistics, (2) medical services, (3) public service (incl. defence force), (4) science & technology, (5) training & education services

* Welch's ANOVA; did not satisfy Levene's test for homogeneity of variances.

† Effect size for Welch's one-way ANOVA (Carroll & Nordholm, 1975). All effect sizes are calculated using ω^2 for comparison.

4.4.4 Critical thinking word categories under-represented compared to Bloom's Taxonomy

As no industry appears to be statistically significantly different in terms of word usage, a better comparison is the differences in word usage between categories themselves. For a fair comparison, the number of instances of each word category is divided by the size of that word category such that larger categories are not unduly weighted. In each case we divide by the number of words from that category that appeared at least once in the advertisements. Results for the 'science and technology' industry are presented in Table 4-4. These findings suggest a weighting towards the use of Bloom's Revised Taxonomy '*create*' and explicit CT indicator categories.

Table 4-4. Word category equivalent instances for the 'science & technology' industry

Variable	**Mean instances per advertisement**	**Category size***	**Equivalent instances**
Bloom's – 'create'	4.54	191	0.024
Bloom's – 'evaluate'	0.74	63	0.012
CT explicit indicators	0.21	9	0.023
CT actions	1.20	64	0.019
CT standards	0.79	47	0.017
CT metrics	0.49	25	0.020

* Number of words in each category that had at least one instance in any job advertisement.

4.5 Discussion

The research finds diverse relationships between each of the word categories and job advertisements for graduates in our context. Beginning with category-category correlations, these findings may indicate a potential relationship between these disparate categories of words within the corporate context, especially between Bloom's Revised Taxonomy (create and evaluate) and literature-defined conceptions of CT. This goes some way to validate the CT metrics as Pearl *et al*. (2018) defined these as being industry-aligned rather than derived from a pedagogical or philosophical approach to CT, like Facione (1990) and Paul and Elder (2008).

Curiously neither the advertised salary nor company size appeared to be associated with usage of any of the word categories. Considering the small number of job advertisements providing salaries, we are reluctant to overclaim the significance of these findings however it would appear that higher paid jobs are less inclined to advertise using explicit

CT indicators nor the CT metrics. A potential explanation for this may be that the analysed jobs are all targeted at a graduate level with a commensurate level of expected responsibility and so would perhaps exhibit a similar level of word category usage. CT has been indicated as a core competency in managerial positions within organisations (Müller & Turner, 2010), and is being actively developed within management classes (Athanassiou, McNett, & Harvey, 2003). Having selected those advertisements that are not at the managerial level, we anticipate that these graduate roles may not yet explicitly require CT as a core skill. As employees then progress through the organisation it stands to reason that higher roles would then require more CT-style behaviours and traits. However, considering the lack of correlation of salary with any word categories, we suspect this observation may be an artefact of the data and warrants requires further investigation. Even larger companies with presumably better resourced HR departments did not show greater tendency to use Bloom's Taxonomy nor CT words in their job advertisements. Due to limited correlations, we suspect these findings are an artefact of the data rather than a true finding. Naturally, this analysis is limited to publicly listed companies who report annual operating revenue; not all companies had operational revenue listings on the Mint Global database, and so were excluded from this part of the analysis. We would ordinarily have expected larger companies to have better resourced HR departments which would lead to advertisements with greater informativeness. This was not evidenced in the data. Further study into the remaining companies would allow for further investigation into this observation.

Although there is no association between industry and word category usage, the range of usage between categories is enlightening. Bloom's Taxonomy - 'create' and explicit CT indicators are almost twice as likely to be used than Bloom's Taxonomy - 'evaluate'. It would appear that across these industries, graduates are much more likely to be asked to 'test', 'develop', and 'write' rather than 'validate', 'evaluate', and 'prioritise'. It is interesting to note that of all the CT-related categories, the explicit CT indicators appear most frequently. The lack of representation of the more nuanced CT definitions supports the findings of Penkauskienė *et al*. (2019) and Pearl *et al*. (2018) when looking at industry conceptualisation of CT. In both those studies, the researchers found employers to have poorly expressed understandings of CT in their contexts and the employer found it hard to concretely articulate what CT means in the workplace. This is an opportunity for universities to provide input to industry by training students who are literate in CT concepts and can drive a change in language use around CT.

A final implication of these findings is that while industry has made repeated requests for improved thinking (especially CT) skills in graduates (Prinsley & Baranyai, 2015), these requests are not necessarily being borne out in the job advertisements that graduates are likely to encounter. Without the explicit indication through these advertisements that these skills are desired, there is an increased imperative for educators to reinforce the importance, and explicitly indicate opportunities for students to improve their thinking skills throughout their degree. While there has been much input over several from industry into curricula, perhaps these findings present an opportunity for the university sector to provide feedback to industry around their recruitment practices.

4.6 Limitations and further work

As previously noted, a word count strategy is a non-ideal approach to analysing texts. We avoid concerns around the inability to detect irony and sarcasm (an often-cited limitation of a word count strategy) by focussing on a homogenous data source, namely job advertisements. Additionally, such a large dataset compels us to rely on a simpler approach to analysing texts. Notwithstanding, this is a probabilistic method of analysing word usage in that it is possible to identify groupings of job advertisements that are either more or less likely to use specific categories of words. These categories can then undergo further analysis if desired. So further work in this area should follow-up with select industry partners to determine how well their advertisement met their actual expectations around the skills and abilities of the person they eventually hired.

As previously noted, an additional analysis of changes to the use of these word categories across increasingly senior roles warrants requires further investigation. This would be well supplemented by further refining the analysis of company size against word category usage through collecting publicly available tax data. Further work should also consider whether these findings translate internationally or are confined to our Australian context. As our dataset also includes large multinational companies, we cannot control for local variances and practices around recruitment. Additional work should also expand to other science, technology, engineering, mathematics, and medical sciences (STEMM) disciplines to investigate these same trends.

4.7 Conclusion

This research examines the explicit use of Bloom's Taxonomy and CT words in job advertisements aimed at graduate STEMM students in our context. This study finds that graduates in our context can expect similar levels of word category usage regardless of the industry they enter, the expected salary, company size, or permanency. There appears to be some way to go in companies explicitly utilising CT words in their recruitment. Continued collaboration between industry and universities will support the improvement of curricula and graduate work readiness. Without the explicit indication through these advertisements that these higher-order thinking skills are desired, there is an increased imperative for educators to reinforce the importance, and explicitly indicate opportunities for students to improve their thinking skills throughout their degree. While there has been much input from industry into curricula, perhaps these findings present an opportunity for the university sector to provide feedback to industry around their recruitment practices.

4.8 Acknowledgements

We would like to acknowledge the invaluable support of Ms Michelle Doherty, Mr Brandon He and Mr Jeffrey Tran in the data collection phase of this project. We also acknowledge the technical and coding support of Mr James O'Shannessy in the analysis phase.

Postface

Findings from this chapter reinforce the idea that industry is not clearly articulating CT skills requirements to prospective employees. In other words, industry says they want CT skills but are not explicitly asking for them. This finding supports the need to develop a common language around CT. Perhaps by engendering a common language in students, these concepts can be slowly embedded into the workforce. Hopefully this is a by-product of the work of this dissertation.

Author's note: Following publication of this chapter, I became aware of a publication that utilised machine learning and natural language processing to analyse the language used to recruit Ph.D. graduates into non-academic positions. This article outlines a promising alternate approach to handling large volumes of data of this type. Future researchers undertaking similar work should consider the approaches used by Mewburn, Grant, Suominen and Kizimchuk (2018) to analyse large datasets.

Section 2

Assessing Critical Thinking in the University Context

Chapter 5

Efficacy of a Commercially-Available Critical Thinking Assessment

Preface

Prior to developing a completely new test of critical thinking (CT), it was sensible to review currently available tests. We want to know whether currently-available tests are sufficient in measuring CT in our students. This study uses one of the most available group of CT tests. Time and cost prohibited us from investigating more tests, so this particular group of tests was chosen as most representative being as it is widely investigated for use in the STEMM disciplines.

Chapter Contents

This chapter is under consideration for publication in a peer-reviewed journal.

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Sounding caution on critical thinking tests in STEM: An investigation of the California Critical Thinking Skills Test

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Abstract

The push for developing critical thinking (CT) skills in undergraduate science, technology, engineering, mathematics, and medicine (STEMM) disciplines at the university-level has led to the need to assess these skills within university courses. A lack of clear definition of CT in turn leads to a wide range of CT assessments each based on various conceptualisations of CT. The California Critical Thinking Skills Test (CCTST), and Disposition Index (CCTDI) are two widely used such assessments. This research investigates the ability of the CCTST and the CCTDI to validly measure CT skills and dispositions over four year levels at an Australian university. In total, 92 students undertook the CCTST and the CCTDI twice in a pre-test/post-test experimental methodology. The CCTST had two test forms, while the CCTDI had one. A small group of 13 students participated in a focus group to give their perceptions of these tests. The paired pre-test/post-test findings indicated that while the CCTST and CCTDI could detect changes to CT skills and dispositions within each year level, over a twelve-week period, these tests were not able to detect changes to skills and dispositions when analysing between year levels. Findings from the focus group indicated that a lack of motivation in taking these tests may have resulted from the CCTST being non-contextual and not reflecting the type of work that students perceived they would be doing once they graduated. Students also reported identical questions between the pre-test and the post-

test indicating a potential threat to the CCTST's validity. Further findings and potential future research opportunities are discussed.

5.1 Introduction

In recent decades the development of critical thinking (CT) skills has become an increasing focus of undergraduate syllabi. Universities in Australia and globally have listed CT as a core graduate competency or graduate outcome alongside other so-called 'soft skills', such as teamwork, communication and digital literacy. Australian institutions frame these variously as 'graduate attributes' (Bond University, 2018; University of Adelaide, 2018), 'graduate learning outcomes' (Deakin University, 2018), or 'graduate study skills' (University of Melbourne, 2018). Specifically, within the STEMM (science, technology, engineering, mathematics, and medicine) disciplines, the development of CT skills in undergraduates has become an explicit intended outcome of many of these courses (Flores, Matkin, Burbach, Quinn, & Harding, 2013; Maxwell, Scott, Macfarlane, & Williamson, 2010; Oliver *et al*., 2010; Prinsley & Baranyai, 2015). This push for teaching CT skills is very much in-line with the desires of employers from the science, technology and engineering fields with strong CT skills being seen as key to post-education employment (Hernández-March, Martín del Peso, & Leguey, 2009; Nicolescu & Pun, 2009). In the Australian context a 2015 Deloitte Access Economics of Australian industry survey found that 92% of surveyed professional, scientific, and technical services desire CT in their STEM-qualified employees (Prinsley & Baranyai, 2015).

5.1.1 Critical thinking in pharmacy and pharmaceutical science education

Within Australia, the UK and the US, CT is enshrined as a standard in the training of new pharmacists. The Pharmaceutical Society of Australia talks about 'critical evaluation' skills as a means to review the quality and efficacy of information (Pharmaceutical Society of Australia, 2010). The General Pharmaceutical Council in the UK uses a broader approach to what they term 'critical appraisal' skills around evaluation of literature but also analysing evidence (in a clinical setting) and learning from one's errors through self-reflection (General Pharmaceutical Council, 2011). The Accreditation Council for Pharmacy Education in the US directly refers to 'critical thinking' and 'critical analysis' skills in degrees leading to a doctorate in pharmacy (Accreditation Council for Pharmacy Education, 2015). While the specific language use differs, the general theme of CT covers all three sets of standards of pharmacy education. None of these standards are prescriptive in their approach to the teaching and assessment of CT, rather leaving the teaching to the discretion of the institutions. To provide formative feedback on CT skills to students, some universities and colleges have employed commercially-available CT assessments. Of additional interest to institutions is the possibility that CT may act as a predictor of pharmacy student academic success and in-clinic performance (Allen & Bond, 2001).

5.1.2 Defining critical thinking

A key difficulty in studying CT and its effects is the lack of clear definition of the term. Due to the complexity of defining and measuring CT, many approaches and frameworks exist. Among modern conceptions, CT has been considered as being ‘purposeful’ (Halpern, 1998, p. 450) of ‘reasonable reflective thinking’ (Ennis, 1993, p. 180) in the form of a series of actions that a critical thinker undertakes. Facione (1990) defines CT as a set of those actions that a critical thinker undertakes and further considers one’s disposition towards using CT skills. That is to say that it is not sufficient that one knows how to critically think, but that they are inclined to critically think when appropriate. Comparatively, some theorists perceive CT as less of a set of generalisable processes and skills, instead contextualised thought that adheres to ‘criteria and standards’ (Bailin, 2002, p. 368).

There is ongoing debate about whether CT as a general skill can be applied (transferred) to novel situations (Ennis, 1989; McPeck, 1990; Perkins & Salomon, 1989) or even the degree to which this transfer of skills is currently being done (Davies, 2016). The contrary position is that CT skills are specific to the context in which they are taught. Halpern (1998) describes the goal of CT instruction as being able to transfer these skills out of classroom into “real-world” settings. Accordingly, she sees the assessment of CT then as needing to be ongoing and conducted in various scenarios that should be requiring the higher-order thinking that CT encapsulates (Halpern, 1998). Transferability may be limited by a student not recognising that their CT skills are appropriate in novel situations (Bransford, Brown, & Cocking, 2000; Halpern, 1998). One way this may be achieved is using authentic examples that reflect a situation in which the student would be required to utilise their CT skills. In this way pharmacy curricula have seen the introduction of problem-based learning (PBL) (Cisneros, Salisbury-Glennon, & Anderson-Harper, 2002) with initial positive indications of its effectiveness (Hogan & Lundquist, 2006; Jacob, Dhing, & Malone, 2019). Similar findings have been reported more broadly in STEMM (Beier *et al*., 2019; Kingston, 2018; Li, Wang, Zhu, Zhu, & Sun, 2019).

5.1.3 Assessing critical thinking at university

Two widely used, and researched, assessments in pharmacy and STEMM are the California Critical Thinking Skills Test (CCTST) and the California Critical Thinking disposition Index (CCTDI), which are both based on the theories of Facione (1990). Work has previously been undertaken looking at correlation between the CCTST and other academic or socioeconomic measures (Danielson, Schwartz, & Lippmann, 2015), the efficacy of translations (İskifoğlu & Ağazade, 2013; Yeh, 2002), and reviews of the CCTST and the CCTDI (Kakai, 2003; Walsh, Seldomridge, & Badros, 2007). Research on the use of the CCTST and CCTDI in pharmacy have yielded mixed results with some finding no statistical gain (Cisneros, 2009) and others finding a mild positive gain (Miller, 2003) during pharmacy education. This research lacks a consideration of the efficacy of the CCTST and CCTDI as a measurement tool within pharmacy, and STEMM more broadly.

Additional to the efficacy of a test, research on test-taking behaviour has indicated a large determinant of performance lies in the test takers' motivation. One aspect influencing motivation is the degree to which the content of the test is perceived, by the test-taker, to be related to the content of their job; that is, the degree to which the test has sufficient *face validity*. In one study, Chan, Schmitt, DeShon, Clause, and Delbridge (1997) considered the effects of the face validity of a test on test-taking motivation and found that motivation was mediated by perceived face validity. In measuring CT specifically, Liu, Mao, Frankel, and Xu (2016) found differences in test-taking motivation lead to an "alarmingly large" performance gap between the highly-motivated and lesser-motivated respondents. Liu *et al*. (2016, p. 691) notes that the concern around motivational impact for low stakes testing is an area of ongoing research interest.

5.2 Aims

This research will investigate the validity of the CCTST and CCTDI over four year levels at an Australian university. This study investigates the development of CT skills and dispositions of students undertaking the Bachelor of Pharmaceutical Science (BPharmSc), double bachelor degree with Bachelor of Engineering (BPharmSc/BE) and students in the

Bachelor of Biomedical Science (BBSc). The validity of the CCTST and CCTDI will considered by addressing the questions:

1. Does the CCTST and CCTDI validly and reliably measure a change of CT skill and disposition across and within year levels?
2. Are the measurements of the CCTST and CCTDI mediated by test-taker characteristics?
3. Do student perceptions of the CCTST and CCTDI indicate strong test-taking engagement and motivation?

5.3 Instruments

This study utilised the California Critical Thinking Skills Test – Numeracy (CCTST-N) (a derivative of the CCTST with extra focus on numerical reasoning) and the California Critical Thinking Disposition Index (CCTDI). In our communications with the test publisher, we were assured that the CCTST-N and CCTDI, while developed for US students, is applicable and appropriate for use in an Australian STEMM context (personal communication). The CCTST-N is designed to measure CT skills in undergraduate and graduate students (Insight Assessment, 2015b). It measures cognitive skills of *analysis, interpretation, inference, evaluation, explanation, induction, deduction,* and *numeracy*. It is a standardised, 40-item, timed, multiple-choice test. Its Kuder-Richardson value for the overall CCTST-N score exceeds .70 (Insight Assessment, 2015b). The CCTDI measures the dispositions of *truth-seeking, open-mindedness, analyticity, systematicity, confidence in reasoning, inquisitiveness,* and *maturity of judgement*. It is a standardised, 75-item, timed, six-point Likert scale questionnaire. The Cronbach's alpha for the seven individual dimensions lay between .60 and .78 (Insight Assessment, 2015a, p. 56). Two versions of the CCTST-N were used with each version being used for either the pre-test or the post-test. The test publisher indicated that these are different sets of questions (personal communication). The CCTDI was only available in one version which was used for both the pre- and post-tests. The CCTST-N and CCTDI are completed online and marked by the test publisher, Insight Assessment (Millbrae, CA).

5.4 Sample

This study was approved by the university's Human Ethics Research Committee and all testing was conducted with no inducement for participation. Students were self-selecting and were recruited using advertising during lectures. In all instances, these tests were conducted for no reward, reimbursement nor grades. In total 92 students undertook the CCTST-N and the CCTDI. In pre-/post-testing, 62 of the 92 undertook the CCTST-N twice and 56 of the 92 undertook the CCTDI twice. Average age was 20.3 years (*S.D.* 1.2 years), with a gender split of 56.5% female.

In of this study we utilised a modified measure of number of years of study. The equivalent full-time study load (EFTSL) (the equivalent number of years the student has completed, accounting for reduced and part-time study loads) is given as a fractional number of calendar years a student has attended university. EFTSL is rounded up to the nearest whole year providing a more accurate measure of the amount of time a student has been exposed to the university system as it accounts for part-time study loads. To distinguish the use of this measure over calendar years of attendance, a students' year level is denoted as *EFTSL year level*.

Students from each course were combined and analysed due to small sample sizes for the BBSc and BPharmSc/BE. Students undertook these tests for no credit. The tests were made available to all students, but only consenting participant responses were analysed. Demographic characteristics were collected after the end of semester, after the completion of all tests and after the release of exam results. Demographic data included: *age*, *gender*, *course of study*, *GPA*, *WAM* (weighted average mark), *pass rate*, *first-in-family status*, *university entrance rank* (ATAR), and *domestic status*.

Table 5-1. Number of students in each year level, over each discipline.

	EFTSL year level				
Field of Study	1st	2nd	3rd	4th	**Total**
BPharmSc	-	5	39	-	44
BPharmSc/BE	2	-	20	6	28
BBSc	3	-	1	16	20
Total	5	5	60	22	92

Students from BPharmSc, BPharmSc/BE, and BBSc were tested 12 weeks after initial testing. Students undertook the pre-test in the first week of semester and then undertook the post-test thirteen calendar weeks later, including one non-teaching week. Students were undertaking on-campus, face-to-face instruction. Within each course, students undertook the same classes during this 12-week period, none of which explicitly aimed to develop CT skills or dispositions. These classes contained a mix of traditional lecture-style content delivery and/or tutorial-style sessions.

5.5 Method

5.5.1 CT between and within year levels

This study aims to determine the validity and reliability of the CCTST-N and CCTDI. To this end we wish to investigate whether these tests can detect a statistically significant increase in CT skills and/or disposition between year levels. Using a pre-test/post-test design we are able to see the differences in CT skills and/or dispositions between year levels as well as the degree of improvement over the testing window within the year level. The CCTST-N and CCTDI report subscale and overall measures which are paired in a pre-test/post-test design to investigate potential improvements in CT skills and dispositions between the pre- and post-tests. The pre-test/post-test design uses a subset of the full 92 students, as not all students completed both tests. The CCTST-N has 62 paired pre-/post-tests, while the CCTDI has 56 paired tests.

To investigate the between-year level effect, an analysis of variance (ANOVA) was used to compare the year levels' means. For this analysis, the pre-test scores from the CCTST-N and CCTDI were analysed. The subscale and overall scores of each year level were compared using a one-way between-groups ANOVA. These scores were preliminarily tested for homogeneity of variance using Levene's test, as suggested by Pallant (2016).

To investigate the within-year level effect, data from the pre-/post-test conditions were compared using a two-tailed, paired samples *t* test. Again, scores were preliminarily tested for homogeneity of variance using Levene's test.

As detailed in Section 5.1.3, a statistically significant gain in CT skills and/or dispositions using the CCTST would support the findings of Miller (2003), in contrast to those of Cisneros (2009). More importantly this study will look at these findings in the context of our STEMM disciplines. The CCTST-N and CCTDI report subscale and overall scores which were analysed using IBM SPSS Statistics 24 (SPSS Inc., Chicago, IL).

One additional measure reported in this testing is *minutes spent on test*. In validating these tests in our context, students should show similar amounts of time spent in completing both the pre- and post-tests. A statistically significant change in this measure may indicate students finding the post-test either more or less difficult than the pre-test. This is assessed alongside the within-year level effects using a paired samples *t* test.

5.5.2 Effect of test-taker characteristics

As a supplementary investigation we wished to determine whether any confounding factors (institution- and student-level demographics) affected any changes in CT skill and disposition, as measured on the CCTST-N and CCTDI. Subscale and overall scores from the pre-tests only of each year level were compared using a one-way between-groups analysis of covariance (ANCOVA), while considering the effect of institutional- and student-level covariates. This analysis used the full 92 student sample pre-test results.

Skewness and kurtosis were tested for the residuals of each of the scores with skewness between -1.0 and 1.0 and kurtosis approaching zero for all measures. A formal test of normality was not conducted as all measures satisfied skewness and kurtosis measures and the sample size was sufficiently large to satisfy the Central Limit Theorem ($n > 30$) (as suggested by Pallant (2016)).

Before conducting the ANCOVA, a range of tests of assumptions was conducted, as suggested by Pallant (2016). All potential covariates (see Table 5-2) were tested for homogeneity of variances over each year level. We determined the covariate inter-correlations to identify and remove redundant covariates. Next, we considered covariate-subscale correlations to determine whether subscales were proxy measures of the covariates. The interaction effect of the covariate and year level was considered in order to meet the assumption of homogeneity of regression slopes. Only those subscales and covariates which passed these assumptions were then compared using ANCOVA.

Table 5-2. ANCOVA considered test and demographic covariates.

Covariate	Description	Acceptable values
Age	Age at time of testing	
Gender	Institution-collected data	'male', 'female', 'other'
Course of study	Bachelor degree being completed at time of testing; aggregated into study area	
GPA	Grade point average	0.00 – 4.00
WAM	Weighted average mark, average percentage mark of each subject studied, with greater weight given to later years of study	0.00% – 100.00%
Pass rate	Fraction of subjects passed	0.00 – 1.00
First-in-family	Indication whether the student is the first in their immediate family to attend university, self-reported	'yes', 'no', 'no data'
ATAR/ENTER	Australian high school achievement percentile, typically used as university entrance rank	0.00 – 99.95
Domestic status	Domestic or international student	'domestic', 'international'

5.5.3 Student perceptions and motivation

Students who undertook both pre- and post-testing were invited to participate in a semi-structured focus group session probing their perceptions of the CCTDI and CCTST-N. This session encouraged free discussion with minimal intervention by the researcher. Students were asked to discuss the CCTDI and CCTST-N. They were then prompted to reflect on how the CCTDI and CCTST-N related to their studies and their anticipated post-graduation employment. This session was conducted by a non-teaching researcher who had not conducted the CCTDI and CCTST-N tests. The session was audio recorded and transcribed.

5.6 Results

5.6.1 CT between year levels

Results for the between-year level ANOVA for both the CCTST-N and CCTDI can be found in Table 5-3. The overall and subscale measures were tested as dependent variables, and the student EFTSL year level as independent variable. One-way between-groups ANOVAs found no statistically significant difference between pre-/post-test scores for any measures of the CCTDI and CCTST-N. Accordingly, no post-hoc test was conducted.

Table 5-3. Means, standard deviations, and one-way ANOVA for the effects of EFTSL year level on CCTST-N and CCTDI measures.

Variable	Year 1		Year 2		Year 3		Year 4				
	M	SD	M	SD	M	SD	M	SD	F	p	η^2
CCTST-N Measures									$F(3, 59)$		
Overall	77.50	5.97	79.43	6.66	77.31	6.41	77.00	3.56	.27	.845	.01
Analysis	76.50	4.36	76.43	8.36	79.55	8.22	75.30	6.34	1.05	.377	.05
Inference	74.50	7.14	81.14	6.18	79.64	7.34	77.80	5.14	.99	.403	.05
Evaluation	76.25	5.50	76.00	7.17	73.90	7.37	77.50	6.45	.82	.489	.04
Induction	76.50	5.75	78.57	8.62	78.38	7.72	80.00	4.08	.24	.865	.01
Deduction	77.75	6.24	79.14	7.08	77.40	6.47	74.80	5.69	.71	.553	.03
Interpretation	81.75	13.62	78.43	8.02	79.21	7.74	80.50	7.12	.21	.887	.01
Numeracy	74.25	6.50	78.29	7.30	75.31	8.91	77.40	6.75	.42	.739	.02
Explanation	74.75	8.77	77.86	6.31	78.69	7.68	75.00	8.29	.84	.480	.04
CCTDI Measures									$F(3, 53)$		
Overall	308.3	24.19	296.5	37.33	300.5	26.35	294.0	21.24	.31	.818	.02
Truth-seeking	37.00	7.07	35.33	6.77	35.53	6.77	36.44	5.70	.10	.958*	.01
Open-mindedness	43.50	6.61	42.83	8.89	44.61	4.38	43.89	6.45	.23	.876*	.01
Inquisitiveness	55.25	3.20	49.50	5.54	48.92	4.16	47.11	4.96	.27	.028*,†	.16
Analyticity	43.00	2.71	45.17	6.80	45.61	4.32	45.00	3.32	.44	.727*	.02
Systematicity	40.75	5.12	39.83	5.35	39.82	5.96	39.00	6.25	.09	.966*	.00
Confidence in reasoning	47.25	8.06	42.67	7.34	42.71	5.22	42.56	5.10	.82	.490*	.04

Variable	Year 1		Year 2		Year 3		Year 4		F	p	η^2
	M	SD	M	SD	M	SD	M	SD			
Maturity in judgement	41.75	4.19	41.33	7.17	43.37	5.92	40.00	3.39	.99	.404*	.05

* Measure violated Levene's test of the assumption of homogeneity of variances. Significance value is Brown-Forsythe test of equivalence of means, as suggested by Pallant (2016).

† Significant at the $p < 0.05$ level (CCTDI *inquisitiveness* only).

5.6.2 CT within year levels

Table 5-4. Descriptive statistics of CCTST-N (n = 62) and CCTDI (n = 56) overall result, subscale results, and time spent on test, showing change in mean values between pre- and post-test.

Variable	Pre-test M	Pre-test SD	Post-test M	Post-test SD	***t***	***p***	η^2
CCTST-N Measures					*t*(61)		
Overall	77.51	5.96	79.83	6.57	-3.93	.000*	.20¶
Analysis	78.33	7.83	80.92	6.89	-2.86	.006*	.12‡
Inference	79.19	6.92	79.94	6.79	-0.89	.375	.01†
Evaluation	74.86	7.10	82.95	7.42	-8.32	.000*	.53¶
Induction	78.54	7.16	81.43	7.97	-3.18	.002*	.14¶
Deduction	77.21	6.37	76.97	8.18	0.22	.824	.00
Interpretation	79.49	7.93	81.16	7.64	-1.73	.089	.05†
Numeracy	75.90	8.23	79.00	7.78	-2.81	.007*	.11‡
Explanation	77.76	7.67	80.84	7.99	-3.46	.001*	.16¶
Minutes on test	50.46	6.49	49.97	6.53	0.72	.475	.01†
CCTDI Measures					*t*(55)		
Overall	299.56	26.28	313.28	28.08	-4.66	.000*	.26¶
Truth-seeking	35.75	6.48	38.05	6.28	-3.38	.001*	.16¶
Open-mindedness	44.23	5.33	44.93	4.82	-1.27	.209	.03†
Inquisitiveness	49.14	4.65	50.49	5.32	-2.39	.020*	.08‡
Analyticity	45.28	4.35	47.25	5.45	-3.31	.002*	.15¶
Systematicity	39.75	5.76	41.93	7.20	-3.06	.003*	.13‡
Confidence in reasoning	43.00	5.61	46.56	6.01	-6.03	.000*	.37¶
Maturity in judgement	42.51	5.66	44.16	5.72	-2.77	.008*	.11‡
Minutes on test	12.91	6.29	10.77	2.98	2.94	.005*	.12‡

* Significant result for $p < .05$

† Small effect size as suggested by Cohen (1988) (*cont.*)

‡ Moderate effect size as suggested by Cohen (1988)

¶ Large effect size as suggested by Cohen (1988)

Results for within-year level paired samples *t* tests can be found in Table 5-4. The CCTST-N pre-/post-test results (Table 5-4, n = 62) indicated that the changes in all subscales were significant except for *inference* (p = .38), *deduction* (p = .82), *interpretation* (p = .09), and *minutes on test* (p = .48). Likewise, In the CCTDI pre-/post-testing (Table 5-4, n = 56) all subscales were found to be significant, except for *open-mindedness* (p = .21). Notably, *minutes spent on test* was significantly shorter for the CCTDI between pre- and post-testing (ΔM = -2.14 minutes, t (55) = 2.94, p < .05, two-tailed) with the effect size (.12) considered moderate as per Cohen (1988).

5.6.3 Effect of test-taker characteristics

The between-year level dataset was subjected to a one-way, between groups ANCOVA with the overall and subscale measures of the CCTDI and CCTST-N as dependent variables and student EFTSL year level as independent variable. We considered the following confounding variables: *age*, *gender*, *course of study*, *GPA*, *WAM* (weighted average mark), *pass rate*, *first-in-family*, *ATAR*, and *domesticity*. *GPA* and *WAM* correlated very strongly (r > .95); only *GPA* was retained. *Age* and *GPA* violated the assumption of homogeneity of variances and thus were both removed. In total, *age*, *GPA*, and *WAM* were removed prior to conducting the ANCOVA. Preliminary checks were conducted to ensure there was no violation of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariate.

Only one ANCOVA comparisons was found to be statistically significant. The comparisons of *inquisitiveness* and *pass rate* (F (3, 53) = 3.27, p = .03, partial η^2 = .16) was statistically significant between year levels. That is, after adjusting for *pass* rate, there was a significant difference on the *inquisitiveness* measure between year levels. The effect of the *inquisitiveness* X *pass rate* interaction was large, as indicated by the partial η^2 values (Cohen, 1988). With a lack of other statistically significant results, having controlled for the above listed covariates are not significant confounding factors affecting the CCTST-N/CCTDI results when comparing between year levels.

5.6.4 Student perceptions and motivation

The semi-structured focus group session (n = 13) took place after the post-tests. Participants were third-year BPharmSc students. We acknowledge that this group does not represent the breadth of groups who undertook the CCTST-N and CCTDI however does provide an indication of student perceptions.

It is worth noting that the BPharmSc course does not contain explicit instruction in CT. The course, at the time of testing, implicitly develops CT skills within a workplace context through four-week and twelve-week work placements in relevant industries. Of the focus group participants, all had undertaken at least a four-week industry placement. We are confident that these students have some insight into the skills and activities they will be faced with when they graduate and the use of CT both within and outside the university context.

5.6.4.1 Perceived vs true answers

The biggest concern in both the CCTST-N and CCTDI was the need to give a single definite answer. This was particularly acute in the CCTDI in which students were required to respond on a six-item Likert scale; '*…they had two parts to agree. Like I'd agree with the first part but not the second.*'

A concern was raised by multiple students feeling compelled to give the answers that they perceived to be most correct, even when those answers did not accurately reflect their CT dispositions:

> *"Exactly some [of the answers] are absolutes … maybe in a work setting or a group project setting you would consider everyone's opinion but you can't really answer what you would do in every situation you encounter."*

5.6.4.2 Difficulty in transferability

One student discussed how their CT could be applied outside the classroom:

> *"That's what I think critical thinking is. … I think it [is about] not making assumptions: just analysing the data that's given to you, not what you feel, and analysing the situation."*

Other than this, students did not draw a link between the CT tests and their studies nor their anticipated graduate work. Generally, students were reluctant or unable to discuss what precisely constitutes good or bad CT. While there was mention of a perceived link between good CT and good marks at university, no student could provide a concrete example of utilising CT outside of a university setting. When further prompted about the link CT (as they understood it) and working in industry, these students took a cynical view of how they might use CT to secure a job:

> *"I think it will depend on the situation like if you don't understand the question. You can think about the answer they want to hear not necessarily what you think.*

But you can pick-up from critical thinking what you think they want to hear and say that."

Without reference to the measures in the CCTST-N, the students appeared to have a conception of CT as a problem-solving technique. They gave examples of how they felt CT might enter into their workplace:

"I think mainly not so much getting a job but once you have a job … something like analytical chemistry I think may it suits that you can try and tease out what's really going on and why it's happening."

"If you're doing your own research you have no idea what you're doing so then here's an approach I can take to take me to where I want and so you start thinking okay is this a logical step … and you move on."

5.7 Discussion

5.7.1 CT between and within year levels and effect of test-taker characteristics

These results show that the CCTDI and CCTST-N can measure a statistically significant increase in CT skill and disposition within a year level over twelve weeks on most subscale measures (Table 5-4), with all significant results being reported having moderate or large effects. Again, we reinforce that study participants did not undertake activities to increase or enhance CT skill or deposition. Furthermore, through their courses, students will not have been exposed to any formal CT courses that the university offers. Curiously these increases in skills and dispositions occur separate from any targeted or intended intervention and are probably a consequence of the students' course. Whether this is due to specific units of study that occurred over the twelve weeks, or an acclimatisation to the testing instrument remains a topic of further enquiry. However, it does indicate that students have apparent improvements in CT skills and dispositions even over this short time period.

Curiously these results are not translated when looking across year levels. This is in direct contradiction to results found using other CT tests, as reported by Mayhew *et al*. (2016) in which a four-year tertiary degree would be expected to lead to a nearly 0.5 standard deviation gain in CT skill between year levels, and similar results found by Huber and Kuncel (2016). ANOVA results (Table 5-3) report almost no statistically significant differences between the year levels. For the CCTDI, students spent on average 16% less time on the post-test and may indicate they were becoming attuned to the test or the testing conditions, potentially affecting post-test results. We acknowledge that students may also have become less motivated to complete the test however this is not supported by the improvement in post-test results. For the CCTST-N the decrease in time spent on the test was not significant. What was not tested here was whether the largest effects (increase in CCTDI *confidence in reasoning*, and increase in CCTST-N *evaluation*) can be attributed to specific tasks or assessments during the semester.

Having controlled for *time spent on test*, *gender*, *course of study*, *pass rate*, *first-in-family status*, *ATAR*, and *domestic status*, none of the measures from the CCTDI nor CCTST-N became statistically significant between year levels. Neither the CCTDI nor CCTST-N could detect a significant difference of the CT skills or dispositions between year levels in our context. These conclusions are supported by the statistically insignificant results of the ANCOVA analyses showing no demonstrable link between the subscales/overall score and any of the demographics selected in our study.

In explaining these results, it is worthwhile to consider the similarities and differences between these groups. The pre-test/post-test cohort was comprised almost two-thirds of third-year BPharmSc students and one-third BPharmSc/BE students. These two cohorts undertake a common first and third year, with the engineers completing introductory engineering units in their second year instead of further biology and chemistry studies. The BPharmSc has a strong chemistry and biology foundation in its first year and tends toward instrumentation and data analysis in later years. This type of content is similar to the BBSc students who completed the single instances of CCTDI and CCTST-N. In none of these STEMM disciplines is CT taught explicitly. What was not able to be controlled during the ANCOVA testing was academic ability. Ideally GPA would play this part, however we are aware that first-year students may have been unduly affected as first-year GPA may be affected by students adjusting to the university system (Postareff, Mattsson, Lindblom-Ylänne, & Hailikari, 2016). The next choice, ATAR, does not have this concern. The ATAR does have disadvantages in that it is a percentile ranking of a student's high-school ability and so caution must be taken when comparing ATAR scores between years.

Our findings are in-line with those of Leppa (1997). Leppa's study looked at the use of the CCTDI for use on nursing students. While we acknowledge that the CCTDI have undergone revisions in the preceding years, our results echo Leppa's in that the CCTST-N subscales indicated no statistically significant gains over ten months. Leppa's use of the CCTDI was less problematic than her use of the CCTST-N. Interestingly, one of her main conclusions is that the "test did not fit with our nursing program or with our … student population", with specific criticism of the CCTST-N being "the acontextual nature of the standardized test … was not a good fit for our program" (Leppa, 1997, p. 30). We note similar criticisms in the following section.

5.7.2 Student perceptions and motivation

A remaining concern is student perception towards the CCTST-N and CCTDI and how this may adversely affect their motivation to undertake the test. Students could not articulate a connection between these tests and university studies, or post-graduation employment. Although unexpected, it was encouraging to see students critically reflect on the test-taking experience. Students reflecting on their own CT skills showed a maturity and awareness aligned with the expectations of self-reflection suggested by Facione (1990) and other CT theorists. The focus group criticisms suggest a lack of motivation when undertaking the tests. This reflects similar views and concerns voiced by Macpherson and Owen (2010) and Liu *et al*. (2016, p. 689). In particular, the latter paper describes a 'significant and substantial effect' of motivation on test scores. It is possible then that the true increase in CT skills and disposition is greater than what was found in this study. This is one area for future consideration in our context. Students felt that they would benefit from being provided with the 'correct' answers. One striking observation is that students appear to believe that there is 'one best answer' or 'one correct approach' to CT rather than conceptualising CT as a range of thought processes or problem-solving approaches. In an industry-context this is specifically captured by the observations of Pearl, Rayner, Larson, and Orlando (2018) in that industries in this field see one aspect of CT as being the creation of multiple potential solutions to a problem. This industry approach is counter to the 'one correct answer' structure demonstrated by the CCTST-N.

Nonetheless the feedback from CCTST-N did provide some students with a reflection on their CT skills especially around self-reflection on biases and assumptions. It did become apparent through the focus group that students did not have a strong understanding of CT as a concept. They were unable to articulate what CT means in either an educational or a workplace setting. This is of particular concern as these students had been exposed to a workplace environment through work placements. Additionally, the test publisher notes that in their testing students were not able to recall test items after two weeks (Insight Assessment, 2015b). Our results directly contradict this. This sits on top of the fact that our research utilised two different forms of the CCTST-N. Our subsequent review of both forms of the CCTST-N did find that indeed some questions were identical between test forms. These finding hit at the validity of the CCTST-N as an assessment instrument.

5.8 Limitations and further work

We acknowledge that this study is conducted in our context and so will not necessarily be translatable across other discipline areas nor other STEMM disciplines at different institutions. We note the lack of control around student motivation during test-retest, and also that the participants in the student perception focus group may be biased by containing a disproportionate number of students with strongly-held views, both positive and negative. Further work in this area should consider a much larger sample size over all year levels. This could initially involve a more targeted analysis looking only at one course of study for a full year, rather than a single twelve-week semester. To investigate the effects of test-taker motivation as a moderator of reported CT skills and dispositions, a formal assessment of test-taking motivation should be included immediately after each testing.

5.9 Conclusions

This study aimed to determine the validity and reliability of the CCTST-N and CCTDI in our context in terms of their ability to detect changes in CT skills and dispositions within year levels, over the period of a twelve-week semester, and between year levels. Our research found that the CCTST-N and CCTDI could detect increases in skills and dispositions on most subscale measures with moderate or large effect sizes. Yet while changes are detected *within* year levels, there was no such improvement *between* year levels. Taken in combination, these results paint a confusing picture as to whether our students are improving or not. Follow-up research should review this result on a larger scale in our context. Nonetheless these findings indicate that the CCTST-N and CCTDI was not an effective tool to measure an expected gain in CT skill and disposition across the range of degrees and year levels studied herein. Considering the 12-week timeframe between testings, we suggest that the gains seen within-year levels is likely due to acclimatisation rather than true CT skill development. This observation is in line with the lack of between-year level improvements and is further encouraged by the participants' noting that some questions were kept identical between tests. In short, this raises cautions as to the use of these tools in assessing CT in STEM.

Additional investigation into test-taker motivations suggested that results may have suffered from a lack of test-taking motivation. Surface analysis of feedback from students was that the test did not reflect the work that they perceived they would be doing when working in industry, or that the tests were overly acontextual. This is doubtless an artefact of the CCTST-N and CCTDI aiming to be relevant for a wide range STEMM and non-STEMM of disciplines. Also, the observation that students were able to remember questions and responses from both forms of the CCTST-N is in direct contradiction to the claims of the test provider and were in spite of this study using two forms of the CCTST-N. Overall, this research raises questions about the value of these tests in our context and whether they would perhaps be better served by a constructively-aligned assessment of CT skills and dispositions as suggested by Ennis (1989, 1990).

5.10 Acknowledgements

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Postface

This chapter highlighted concerns around one commercially available test of CT. The biggest concern to take from this study is the lack of constructive alignment between the test and the work that students expected to be doing when they enter the workforce. Put more clearly, the content of the test did not adequately align with what graduates expected to be doing when they enter the workplace. This finding encourages the idea of creating a new test of CT that better fits the reality of the workplace.

Chapter 6

Making a Novel Critical Thinking Assessment

Preface

In the previous chapter we considered some of the limitations of one widely used test of critical thinking (CT). This chapter, and the remainder of the dissertation, looks at the creation of an assessment that is better tailored to the needs of students in the Bachelor of Pharmaceutical Science which would be based on the industry-aligned conceptualisation of CT, shown in Chapter 3. This chapter will initially outline one theory of assessment and test validation which will underpin the subsequent development of a novel CT assessment and the validation studies that were conducted. This CT assessment came to be known as the Monash businessThink (MbT) to reflect the key inputs from industry (*businessThink*) around how our students (*Monash*) will be expected to demonstrate and utilise CT in the workplace. The validation of the MbT spans this chapter and the next. In this chapter we will focus on the validation and reliability studies that were qualitative in nature and arose during the drafting stages, whereas the next chapter will focus on the quantitative, statistical assessments of validity and reliability.

Chapter Contents

6.1 Test theory framework

This subsection provides the background theory around test validation. An *assessment tool* (a *test*) is comprised of many *task items*, or *items* (the test's *questions*)[3]. Through testing we want to investigate and measure a behaviour, skill or trait in an individual or a population. Test theory refers to the subject of measurement as a *latent trait* or *latent skill* (denoted by theta: θ). The idea of a trait or skill being *latent* is that the trait is not manifest nor directly measurable, or rather needs to be measured indirectly using an assessment tool (DeVellis, 2012). One's performance on an assessment tool (*X*) can be understood as a function of one's latent skill (θ) and an element of error (*e*):

$$X = \theta + e$$

So, in developing a valid test, we need to understand and minimise the effect of the error term such that one's performance on the assessment tool approximates one's latent skill. No set of validation tests can completely eliminate the error term, however through conducting these validation tests we can build a case for or against the overall validity of the test and a negligible (or not) degree of error.

6.1.1 The elements of error

The error term can be further divided into sources of potential error: (i) quality of the assessment tool, (ii) quality of individual items, (iii) test-taker personal characteristics, and (iv) test-taking habits. Addressing each of these sources of error is the purpose of this chapter and the next. Let us briefly consider each of these sources in turn. Specific validation exercises are drawn from a number of sources (Bland & Altman, 1986; Guion, 1980; Hathcoat *et al*., 2016; Kane, 2006; Lawshe, 1975; Norris & King, 1984; Polit, 2014; Sosu, 2013).

[3] For the purposes of the remainder of the dissertation, I shall use *assessment tool*, and *test* interchangeably and will refer to *task items*, or *items*.

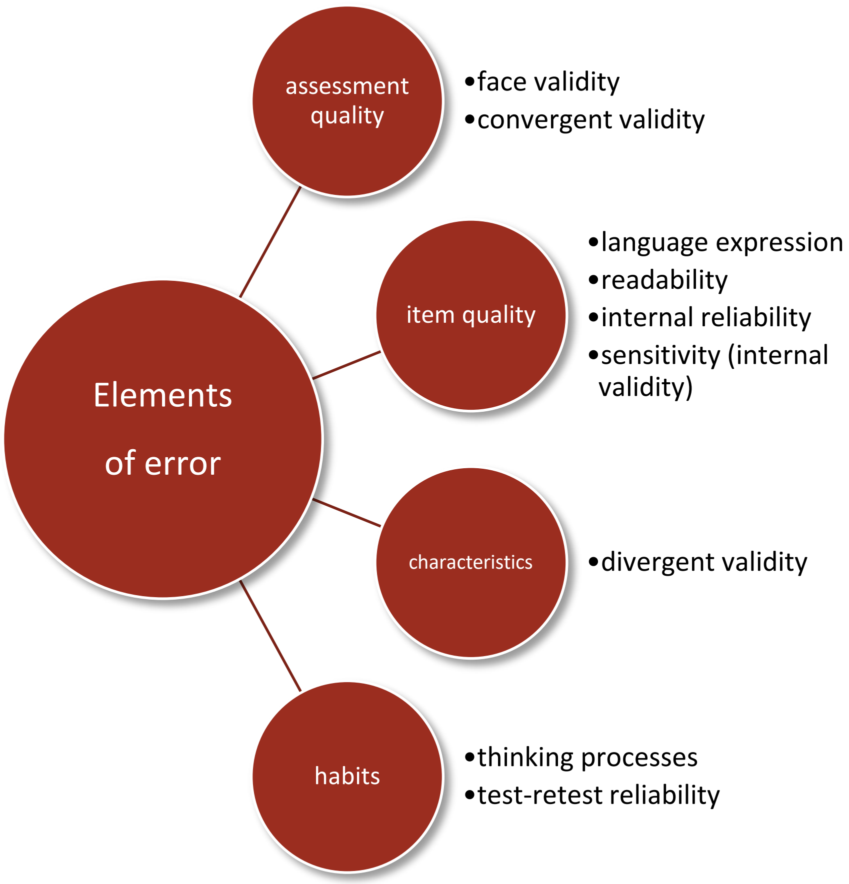

Figure 6-1. Schematic of the elements of error.

6.1.1.1 Quality of the Assessment Tool

The purpose of these considerations is to ensure that the assessment does truly test what it purports to be testing. In essence we wish to answer the question; will the MbT actually be testing the CT metrics that were outlined in Chapter 3? We can assess the *face validity* and *convergent validity* of the MbT to answer this question.

The MbT is structured around two contextual principles; it must closely reflect the types and styles of work that a graduate from our course would reasonably be expected to undertake when they enter the workforce, and it must assess student CT skills in the context of these styles of work. These principles should be made evident during the development and drafting of the MbT through actively trying to replicate a real-world working environment as closely as is practicable. Ideally the MbT would be a form of work-integrated learning in which students would be placed in a company and tackle real-world problems, however this is not a practical option due to obvious constraints. Resorting then to a more traditional assessment, it is evident from the literature that the MbT should try to replicate the same workplace context so as to increase test-taker motivation (Kwan & Wong, 2015). This process is explained further in Section 6.2.2.

Once the MbT is drafted we must then validate that its content is a genuine reflection of industry practice and not simply our perception or imagination of how industry operates (Guion, 1980). We can assess the *face validity* of the MbT by utilising our industry contacts. In this case *face validity* refers to how well the MbT *prima facie* appears to reflect real-world problems in industry that our graduates might need to tackle (Haladyna & Rodriguez, 2013; Lawshe, 1975). Our industry contacts act as subject matter experts in this validation. This process is further detailed in Section 6.3.2.

Finally, as the MbT is intended to measure CT, we conduct a study of *convergent validity*. This study compares the MbT to another pre-validated test of CT. If we assume that both tests are assessing CT in the same way, then it stands to reason that high performance on the MbT should correlate with high performance on the other CT test inasmuch as the scores from these two tests ideally *converge* at the same result (Haladyna & Rodriguez, 2013). In other words, is the MbT testing what it purports to test? This is the approach favoured by Guion (1980). However, as previously discussed, there is a plethora of CT definitions, frameworks and conceptualisations leading to a wide range of CT tests. The MbT is using a unique approach to CT (industry-aligned CT) which, as a result of the chosen industries in Chapter 3, is valid only for our limited context. Section 6.2.1 will show that other CT tests do not assess the same areas as the MbT. As such, this study of convergent validity will provide only a minor indication of the overall MbT validity. The results of this study can be found in Chapter 7.

6.1.1.2 Quality of Individual Items

In determining whether the individual task items are valid, we will consider *language expression*, *readability*, *internal reliability*, and *item sensitivity*. We start by having an experienced external party qualitatively review the items for potentially ambiguities and readability issues. This process is further detailed in Section 6.3.3. As an adjunct, the readability of the MbT is also quantified in Chapter 7.

The major assessment of item quality comes under *internal reliability* and *item sensitivity*, both of which are assessed by determining the difficulty and discriminability of the test items which utilises *Classical Test Theory* and *Item Response Theory* frameworks. In this case, discriminability is the ability for a test item to clearly and accurately discriminate between a high-ability respondent and a low-ability respondent.

When assessing the quality of the test items, we must consider the spread of difficulties of the items such that the MbT overall is neither too difficult nor too easy. A spread of item difficulties allows for better discrimination between high-performing and low-performing students (Haladyna & Rodriguez, 2013). A statistical approach to validating test items utilises Classical Test Theory (CTT) and Item Response Theory (IRT). The CTT approach looks at the assessment in its entirety to determine whether it is valid and able to accurately predict student performance levels (DeVellis, 2012, p. 160). By looking at the assessment as a whole, to gain better statistical predictive power one could increase the number of items thereby increasing the sample size for statistical analysis. It may not be desirable to increase the number of items however, as this may lead to an inappropriately large assessment. On the other hand, IRT analyses the individual test items to determine their predictive ability (Kline, 2005). This approach allows the test designer to alter individual items more accurately rather than introducing more items. Therefore, the IRT can also address the desire to have a range of item difficulties within a smaller number of test items. With a desire to keep the MbT as short as practicable, the IRT approach is favoured (Kline, 2005).

From a quantitative perspective, IRT can report up to three characteristics; item difficulty, item discrimination, and false positives, which we briefly discuss in turn. *Item difficulty* is an indication of the amount of latent trait the respondent demonstrates by correctly answering the item. Identical to the common understanding of difficulty, a higher difficulty indicates a higher amount latent trait (DeVellis, 2012). An analysis of item difficulty alone is also called a *one-parameter logistic model* (1PL, or Rasch model). *Item discrimination* is a measure of how probable the item will discriminate between correct and incorrect responses (DeVellis, 2012). For example, take two respondents one of whom has a latent skill slightly *less than* the test item difficulty, and the other whose latent skill is slightly *more than* the test item difficulty. An ideal item would be able to discriminate between these two respondents with one-hundred percent accuracy. After all, a respondent with higher latent skills should be more likely to correctly answer the item. Conversely, a lower quality item will accurately discriminate less often, be it due to poor item wording, ambiguities, or potentially being off-topic. A still worse situation would be a negatively discriminating question in which a respondent with *higher* latent skill is *less* likely to correctly respond to the item. An analysis combining difficulty and discrimination forms a *two-parameter logistic model* (2PL). The final parameter, *false positives* or *guessing* is an indication of the probability of a respondent correctly guessing the response (DeVellis, 2012). This would be of particular concern for multiple-choice style questionnaires in which respondents have a one-in-four or one-in-five chance of guessing correctly. All three parameters together form the unimaginatively named *three-parameter logistic model* (3PL). In validating the MbT we opt for a 2PL model analysis, the results of which can be found in Chapter 7, with justification for ignoring the *guessing* parameter shown in Section 6.2.2.

6.1.1.3 Test-taker Personal Characteristics

To ensure that the MbT is only measuring CT ability, we have previously discussed comparing performance on the MbT with another validated CT test. To supplement this approach, we also want to ensure that performance on the MbT is not being influenced by other factors which are external to the MbT itself. This study of *divergent validity* considers the effects of other factors that are not CT-related (Haladyna & Rodriguez, 2013). In our context we want to ensure that students are not being unfairly affected by personal characteristics such as English-language proficiency, academic achievement, or age. While the effects of these cannot be completely excluded, we want to ensure that their effects are comparable to literature-reported levels. This process is further detailed in Chapter 7.

6.1.1.4 Test-taking Habits

Lastly, we want to consider any error that might arise from the manner in which the test is completed. The first step is to ensure that students are approaching the test items in the way we anticipated. If specific items lead to erroneous thinking, then that item can be flagged for review or revision. This process is explained in Section 6.3.4.

To further ensure that students are not guessing responses and the MbT is scoring consistently, we administer the MbT twice to students after an intermission of approximately 6 weeks. This is an assessment of *test-retest reliability* (Polit, 2014). This approach is supported by Bland and Altman (1986) who reinforce the importance of consistency of repeated measures when validating an assessment or measurement tool. In their approach the tool can be assessed against itself (*test-retest reliability*) or against a previously validated tool (*convergent validity*). In our case, by comparing the results of these two test instances, we can draw inferences around the robustness of the MbT and whether students are guessing responses. This study is outlined in Chapter 7.

6.2 Developing the Monash businessThink

With an awareness of the types of validation that must be completed, the MbT can be drafted. This next subsection details the process and considerations around drafting the MbT.

6.2.1 Reviewing currently available tests

Before drafting a new assessment tool, it was appropriate to review as many relevant currently-available tests of critical thinking (CT) as possible. The purpose of this review was: (i) to identify any tests that also assess similar conceptualisation of CT, and (ii) to compare the modalities of various tests (*e.g.* essay-style response, short-answer, closed-answer) to identify potential options for the MbT.

A literature review and web search were conducted using the terms "*critical thinking assessment*", "*critical thinking test*", "*university critical thinking*", "*college critical thinking*", "*critical thinking exam*". The literature review was conducted on Web of Science, Scopus, whereas the web search was conducted using Google and Google Scholar. This process identified 76 potential CT tests. Of these, 29 were excluded; ten were aimed at children and/or high school students, seven were not available online (due to lack of licensing options), six were not assessments as such but instead were variously courses or assessment rubrics, four could not be further located, and two were stated as adaptations of otherwise available CT tests. The remaining 47 tests were reviewed against the above stated purposes. A full list of the reviewed tests, and the extracted details, can be found in *Appendix 8. Chapter 6: Review of critical thinking tests*, pg. 257. Tests created by the same group or institution, or with an identical theoretical basis, were considered individually rather than in aggregate as potentially there may be subtle differences between otherwise similar tests.

6.2.1.1 Similar conceptions of critical thinking

The currently-available tests were first compared against the MbT conceptualisation of CT. The MbT is designed to be an industry-aligned assessment of CT skills. These skills are to reflect the CT skills expected of science, technology, engineering, mathematics, and medicine (STEMM) graduates in the workplace. For the 47 tests, each test website stated the intended elements of CT that the tests assessed. These details can be found in *Appendix 8. Chapter 6: Review of critical thinking tests*, pg. 257. If a test is found that contains similar concepts to the MbT, then it may be adapted or utilised in the creation of the MbT.

Table 6-1. MbT metrics with definition.

MbT metric	Definition
Systematicity	A disciplined, orderly approach to the problem-solving process.
Business-sense	An awareness of the constraints of working within the business context, in relation to time, resources, *etc*.
Multiple solutions	Providing multiple viable recommendations/solutions.
Consideration of implications	An awareness and understanding of the effects of one's decision or recommendations.
Identification/ Awareness	To identify issues or problems and determine their component parts, and to identify the conceptual relationships of those parts to each other and to the whole.

Of those reviewed, four tests contained one or more stated element that was similar to one or more MbT metrics. Only the Business Attribute Inventory is based in a business-context, however it is not aligned with the types of work that our graduates would typically be undertaking in their first few years post-graduation. The remainder are similarly not aligned.

Table 6-2. Critical thinking tests with similar elements compared to MbT metrics

Test Name	Provider	Duration and Modality	Relevant Element	Similar MbT Metric
Business Attribute Inventory	Insight Assessment	25-minute MCQ-style	"workplace flexibility"	business sense
GMAT Critical Reasoning	Graduate Management Admission Test	3.5-hour MCQ- and essay-style test	"multi-source reasoning, graphics interpretation, two-part analysis, table analysis, data sufficiency"	systematicity
ICAT Critical Thinking Essay Test	Center for Critical Thinking and Moral Critique	short answer-style	"implications"	consideration of implications
My Thinking Styles	Pearson – Talent Lens	10-minute MCQ-style	"systematic … thought processes"	systematicity

6.2.1.2 Various modalities

Next, we considered the various modes of the available CT tests to identify any patterns of testing that could be used in the MbT. A review of the CT tests shows that the main modality is multiple-choice questionnaire (MCQ) (including other closed-response options). The remaining tests which incorporate an open-response (*e.g.* essay-style or short answer) require the test responses to be returned to the publisher for separate marking or include training for the academic to do the marking themselves. Neither scenario is ideal for the MbT for marking of a large number of respondents.

However, the ideal method of assessing CT involves an assessment of the thinking (or problem-solving) method. Previous research in this area has highlighted the limitations of using closed-response style questions in assessing CT, whereas open-response questions allow the respondent to fully develop and explain their reasoning (Ku, 2009; Scouller, 1998; Stanger-Hall, 2012).

There are multiple examples of MCQ-style CT assessments including commercially-available and bespoke tools. One such bespoke tool is described by Morrison and Free (2001) in assessing undergraduate student nurse CT skills. While Morrison and Free clearly articulate the cost and time benefits of MCQ CT assessments, their shift towards eliciting

CT is through asking respondents to select the 'most important' or 'greatest implication' response. This approach is limited in having potentially subjective responses. Consider a situation where a nurse needs to ask a series of diagnostic questions to a patient. While the nurse will have been taught which questions to ask and when, in a clinical situation it may be more relevant to 'go off-script' and ask a more probing question if the nurse's instinct or experience encourages such an approach. Then by asking student nurses to choose the 'most important' response, Morrison and Free may be implicitly encouraging nurses to stick to the taught approach and supress their instinct or experience. At least in Australia this practice is discouraged. The registered nurse Standard 1.2 calls for registered nurses to "[develop] practice through reflection on experiences, knowledge, actions, feelings and beliefs …" (Nursing and Midwifery Board Australia, 2016). Morrison and Free describe having all responses as being plausible or "relatively possible" but one option being "better than the others" (Morrison & Free, 2001, p. 20). The respondent has no ability to explain their reasoning behind choosing or disregarding certain options (Ku, 2009). In summative assessments, without the ability to justify or clarify one's response, the respondent defaults to the 'expected answer'. Additionally, the assessor implicitly assumes that the respondents are all following the assessor's logic. One remedy to this is either have all plausible options appear at the outset to be equal (and therefore difficult to discriminate between), or have one option stand clearly above the others (therefore enabling respondents to 'game' the assessment).

From a general assessment perspective, Scouller (1998) identified essay-style questions with requiring students to engage in deeper level thinking when compared to multiple-choice style questions. Similar to the findings by Liu, Frankel, and Roohr (2014), only a minority of the 47 commercially-available CT tests studied in this report utilise an open-response format (n = 11) (either standalone, or in combination with closed-response options). We note that the MCQ style of response may lack face validity (Liu *et al*., 2014). While some researchers argue in favour of open-response formats especially in authentic assessments whilst acknowledging the potential for subjectivity in scoring (for example, such as in essay-style assessments) (see: Ashford-Rowe, Herrington, and Brown (2013); Eubanks (2009); Stein and Haynes (2011)), others also argue for the pragmatism of closed-response formats (Downing, 2006; Ennis, 2008; Haladyna & Rodriguez, 2013). Proponents of closed-response format highlight the ease of administration to large groups as a primary consideration. Conversely, critics of this approach note the difficulty in assessing the thought process of the respondent (Norris, 1989). Other criticisms levelled at closed-response formats are the possibility of 'gaming the test' by which highly able students are able to deduce clues to the correct response and in doing so reduce the pool of options from which they need to select. However, the use of well-written questions and responses reduces this possibility (Downing, 2006; Haladyna & Rodriguez, 2013). Complaints that respondents could simply guess the correct response are statistically fallacious. For example, with a minimal increase in plausible distractors, the expected 'score' from guessing decreases significantly (Haladyna & Rodriguez, 2013).

Findings from this initial investigation indicate that no current test assesses the same areas as the MbT while most utilise close-response questioning. The few assessments that incorporate an open-response portion are marked by assessors trained by the test publisher. This leads us to conclude that an appropriate measure of CT must reach a compromise between authenticity and practicality. Ideally the assessment tool will be closed response (to allow for ease of marking) and sufficiently broad so as to prevent inspired guesswork on the part of respondents. Additionally, the questions themselves must then also be limited so that they can fit into a closed-style response questionnaire.

6.2.2 Designing the MbT

A copy of the most recent version of the MbT can be found in *Appendix 10. Chapter 6: Monash businessThink (version 7*), pg. 268.

6.2.2.1 Design considerations

The MbT aims to reflect the types and styles of work in industry. The MbT participant takes the role of a recent graduate in fictitious company that makes an unspecified consumer good. This is similar to roles that our graduates genuinely have undertaken, and conceivably will continue to undertake. The MbT is comprised of two main parts; the *tasks*, and the *auxiliary documents*; respectively a series of industry vignettes each centring on a problem or issue which your manager presents to you, and the extra workplace documents you need to respond to the problem or issue.

In total there are seven tasks that each contain two or more assessment items. Each task comprises one section of the MbT. The auxiliary documents are based on real-world examples and include, amongst others, material data sheets, formulation recipes, and batch records. The auxiliary documents are required supplemental data to respond to the tasks.

From the outset we intend that the MbT can be completed in a single one-hour session so that it can be easily incorporated into current classes. With large cohorts in our courses, we desired to have the tool be automatically marked. This required us to administer the MbT digitally and limited the types of responses that we could collect.

6.2.2.2 Designing questions

While the essay-style approach appeared to lend itself more appropriately to assessing CT skills, the convenience moreover, low running cost of a multiple-choice-style test was taken as the more pragmatic choice. Additionally, prior research around the use of written responses in measuring CT has noted up to “25% of the variance in CT scores was attributed to differences in [written communication skill]” (Hathcoat *et al.*, 2016). This is only one instance, but does indicate a need for caution.

To alleviate the risks of respondents ‘gaming the test’ or correctly guessing the response, the MbT utilises closed-response questions with a very large set of potential solutions. For example, one task requires the respondent to indicate which laboratory tests (if any) they would conduct to collect a prescribed set of data. Of the nine available laboratory tests, the respondents may opt to select any combination of zero to nine tests. As the order of tests is unimportant, there are 512 combinations. Of these, one or more is mathematically optimal and would receive full marks. If desired, the next near-optimal solutions can be given partial marks. With a large number of potential solutions, the respondent is required to engage with the material rather than guessing a solution.

Ideally the respondent may utilise problem-solving or CT techniques to approach this question in a systematic, rather than one-at-a-time ‘brute-force’ manner. Issues around having the respondents justify responses is negated through question design. Most tasks require respondents to find optimised solutions (*e.g.* optimum scheduling, cost, *etc.*) however sub-optimum solutions are still partially scored. This style of tasks does not require the respondent to justify their answers as the responses are mathematically proven optimal or sub-optimal. Nevertheless, of the seven tasks in the MbT, the final two tasks ask respondents to identify a potential cause of a problem and then nominate viable remedies. The first part of these tasks assesses whether the potential cause is a *possible* cause (not necessarily *probable* cause). The second part then assesses whether the chosen remedies will address the selected cause.

The questions themselves were drafted based on the approaches outlined in literature around best-practice for multiple-choice style questions (Haladyna, Downing, & Rodriguez, 2002), and other sources of developing CT assessments (Norris & King, 1984; Sosu, 2013).

6.2.2.3 Contextualising questions

Content for the assessment was drawn from dedicated industry scenarios, and pre-existing discussions taken from the industry semi-structured interviews.

As indicated by Yin (2018), case studies are an appropriate option to investigate "a contemporary phenomenon … within its real-world context". For the purposes of this research, students' engagement and use of CT within the industry context lends itself nearly to Yin's use of case studies as a research tool. To this end, the instrument questions were informed by a series of scenarios that were drawn directly from industry. These scenarios were collected using a modified approach outlined by Yin (2018), as detailed in the following subsections. These scenarios were taken from experiences of problems that graduates can be expected to encounter in companies that hire graduates from our course. Having been drawn directly from industry, the questions derived from the scenarios are intended approximate the experience that a graduate can expect to encounter in the workplace. This data was collected using semi-structured interviews with industry representatives (see Pearl, Rayner, Larson, and Orlando (2018)) (see Chapter 3). These examples of CT in industry were decomposed into a series of tasks and items for the MbT.

6.2.3 Developing MbT questions (MbT version 1)

The question development followed the structure outlined by Haladyna and Rodriguez (2013). This development hierarchy can be summarised as:

Test construct > Task family > Task template > Task Item

The task constructs represent each of the areas that are to be assessed, which in this case are the MbT metrics. The task families indicate a common idea or theme that group the task templates below it. Each task template is the formulaic arrangement of the question/item, showing the variables and the algorithms for creating each task question/item. Lastly the task item is the individual question itself with associated data and details.

6.2.3.1 Task Family

In total, four task families were created;

Table 6-3. Task families

Task Family	Summary
Comparing products	Respondents are required to compare numerical data between two or more products. The data is presented in the form of data sheets. Respondents then select the best choice for the given scenario.
Undertaking tests	Respondents select and schedule tests to collect required data to complete a data sheet. The choice of appropriate test(s) is based on test cost, time required, and results given for test.
Finding root causes	Respondents identify potential issues and location of problems. Respondents will nominate potential solutions.
Following procedures	Respondents investigate test or production procedures. Respondents are required to identify potential issues within the procedures, or mistakes that someone has made in following the procedure.

A fifth task family ('Creating procedures') was originally envisaged but was deemed too difficult to turn into a closed-response style task.

6.2.3.2 Task Template

The task template is the basis for the creation of the final assessment items (Haladyna & Rodriguez, 2013). The templates show the required data for the question, and details of each option indicating why it should or should not be selected. Each template is based on one or more scenarios that arose during interviews with the industry representatives (see Chapter 3). These scenarios arose during discussion of what constitutes CT in their field, as would be reasonably conducted by graduates of the BPharmSc. It is the intention that each template reflects one instance in industry where respondents would be required to demonstrate critical thinking skills. The primary author developed these scenarios which were then validated by industry representatives (see Section 6.3.2).

A template based off the 'Comparing products' family looks at choosing the best product supplier. Respondents are required to select a preferred supplier from three or more options. Specifically, they will be looking at differences in the presented data sheets. Respondents should realise that all options (except one) are viable. The choice then comes down to weighing up price/purity and duration of supplier relationship. This will test their business acumen in determining the most and least important variables to be considering.

An example of a task template is shown below.

Required Data:

- Three or more data sheets of material options of same type but varying properties; from two or three suppliers
    - Products are similar on physical and chemical properties, with no single product being considered better than others
    - All physical and chemical specifications should be within the desired ranges. The number of parameters should be (5 x the number of options; approx. 20)
    - One supplier is newer and marginally cheaper
    - One supplier is long-term (5+ years) relationship w/ company, marginally more expensive, marginally more pure
    - There should be an approximately even division of good and bad properties between the suppliers, such that a student could find 5+ potential reasons why one supplier is better than the others. (*cont.*)
    - Only one material should have no more than one property marginally outside the acceptable specifications.
    - Data sheet should be divided into headers sections: Title Block, Physical Properties, Chemical Properties, Supplier History
        - Chemical and physical properties shall be reported to an appropriate number of decimal places and an error range
- A specifications sheet giving acceptable ranges of some product physical and chemical properties

The details then build into templates for potential questions, as outlined below. Table 6-4 shows the potential question wording, the number of options the respondent can choose from (the number of options (nO) and number of possible permutations/responses (nP)).

For example, the first template question below is asking the respondent to look at the provided data and then rank the choices in order from most preferred to least preferred. At the time of authoring, there was to be two, three, or four options to rank. Selecting two options gives only two possible responses, three options gives six possible responses, and four options gives twenty-four possible responses. Lastly the marking for this question is only dependent on the top-ranked and bottom-ranked options. In a similar way, all the templates are created.

Table 6-4. Example task template

QUESTION	OPTIONS	MARKING
Which sample is the most preferred? Rank the samples in order of preference. [1 = MOST preferred; 4 = LEAST preferred]	All the products/supplies options [nO = 2/3/4, nP = 2/6/24]	Marking for the Top option being the long-term, Bottom option being out-of-spec (*systematicity*)
Considering only your MOST preferred sample (ranked #1), from question above, why should we choose that sample instead of the others? Select the top three (3) headings that justify why we should choose that sample. Rank these three (3) headings in order of importance. [1 = MOST important reason to choose that sample; 3 = LEAST important]	All the variables [Options: choose 3 out of 33 headings] [nP = 32,736] Practically; [Options: 3 of 24] [nP = 12,144]	Marking for selection of highest possible Top 3. Specifically looking for selection of long-term supplier (*business* sense, *consider implications*) Marking for order of Top 3 (did they match our hierarchy?) Business > Physical / Chemical / *etc*. (*business sense*)
Considering only your LEAST preferred sample (rank 4), from question above, why should we NOT choose that sample? Select the top three (3) headings that justify why we SHOULD NOT choose that sample. Rank these three (3) headings in order of importance. [1 = MOST important reason NOT to choose that sample; 3 = LEAST important]	All the variables [Options: 3 of 33] [nP = 32,736] Practically; [Options: 3 of 24] [nP = 12,144]	Marking for selection of lowest possible Low 3 OR Low 2 (+ the out-of-spec) Specifically looking for the selection of the out-of-spec (*business* sense, *consider implications*) Marking for order of Low 3 (did they match our hierarchy?) (*business sense*)

6.2.3.3 Task Item

Lastly the individual items can be created from the template and the marking schema derived. The above template became *Section 2: Questions 5, 6, and 7* in the first version of the MbT.

Each item is designed to have only one optimal response which would attract full marks. However, many items have nearly-optimal responses that could potentially be awarded partial marks. For the purposes of the pilot study and the statistical analyses, it was simpler to award all-or-nothing marks to respondents. Future versions of the MbT could be set up to allow for partial marks to be awarded.

6.2.4 MbT structure (sections and introductions)

It was important to ensure that the questions felt as though they reflected the type of work that a graduate might reasonably expect to do in industry. To enhance this illusion, the MbT gave its instructions in the form of a job acceptance letter, and had each section introduction provide the business context for the subsequent questions. As part of the validation process, industry representatives were asked about the accuracy of these parts. Details of this validation test can be found in Section 6.3.2, below.

6.2.5 Auxiliary documents creation

To better reflect the experience of working in industry, the data that is required to answer each question is given in the form of additional or auxiliary documentation. For the MbT these documents would be; *material data sheets*, *material specification sheets*, *test* and *formulation procedures*, *an equipment booking calendar*, *a production batch record*, and *a piping diagram*.

Once the task templates were developed, the required additional information could be determined. The style of these auxiliary documents is based on real-world similar documents. The data for each sheet was determined in conjunction with the test items. These auxiliary documents can be found in *Appendix 11. Chapter 6: Monash businessThink (version 7) auxiliary documents*, pg. 303.

6.3 Validating the Monash businessThink

Having created a first draft of the MbT, attention now turned to determining its validity and reliability. As discussed in Section 6.1, creating a new CT tool requires a set of validity and reliability studies are undertaken to test the quality of the MbT.

These studies were conducted both during the drafting phase as well as a pilot study. The following schematic indicates when these studies were each conducted and upon which version of the MbT they were done. The remainder of this section describes the various iterations of the MbT, the validity and reliability tests that were undertaken at the given stage, and the changes made in light of the results.

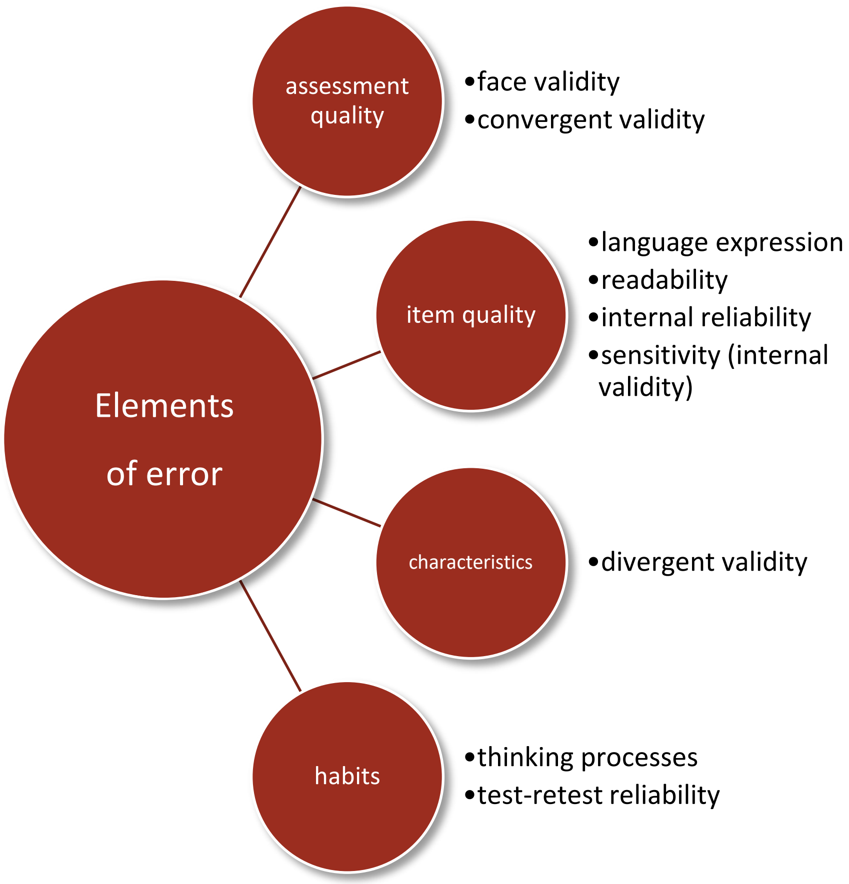

Figure 6-2. Schematic of the elements of error.

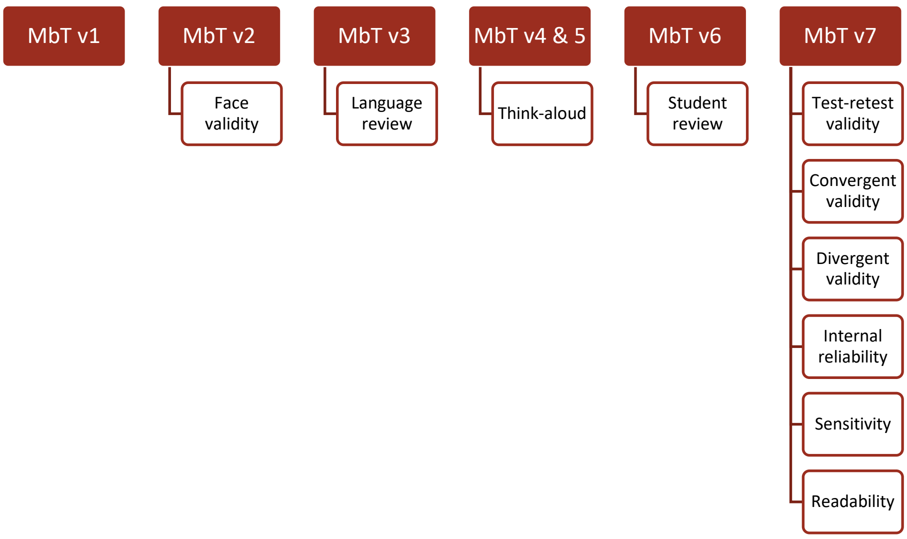

Figure 6-3. Representation of the MbT versions and related validation/reliability studies conducted therein.

6.3.1 Ethics

Conduct of this research was completed with ethics approval by the Monash University Human Research Ethics Committee.

6.3.2 Face validity (MbT version 2)

Prior to pilot testing, the MbT was reviewed by industry representatives to validate its industry alignment (Lawshe, 1975). One of the main precepts of the MbT is that it is ‘industry-aligned’; that it would reflect the type of work that graduates from the Bachelor of Pharmaceutical Science (BPharmSc) would experience within the first three years of industry work. Industry representatives were again surveyed to ensure that the scenarios and auxiliary documents were a true reflection of industry.

We opted for a semi-structured interview conducted in the workplace. This method balanced the needs of our industry respondents and our ability to conduct the semi-structured interviews efficiently. In total, 21 respondents from six companies participated. The companies represent *skincare*, *cosmeceuticals*, *other consumer goods*, and *industrial goods*. Notably there were no companies that represented the pharmaceutical industry. This is not an oversight and instead reflects the reality that most of our graduates do not enter this industry directly after university.

The industry participants represented a sample of convenience of our industry partners. These participants all work for companies with a pre-existing relationship with the Faculty. These companies take our students for in-course placements and have previously hired graduates of the BPharmSc. For practical reasons, the participants from each company were interviewed together.

The participants were self-selecting but were required to:

- have supervised recent graduates of the BPharmSc, where ‘recent’ refers to 1–2 years post-graduation, and
- have at least 2 years’ experience in role(s) similar to those that would be filled by recent graduates of the BPharmSc.

These requirements ensured that the participants had, in our view, sufficient relevant industry experience and contact with our students. Of the 21 participants, four are alumni of the BPharmSc course, two of whom have studied for one year as a peer of one of the main researchers. Due to the group nature of the semi-structured interviews, we do not believe this poses a threat to the validity of the results.

The semi-structured interviews were then broken into three areas of interest: (i) the validity of the CT metrics, (ii) the validity of the scenarios and their questions, and (iii) the validity of the auxiliary documents. A copy of the full series of focus group questions can be found in *Appendix 9. Chapter 6: Industry face and context validation focus group*, pg. 267. The participants were also provided with a copy of the MbT (version 1, including auxiliary documents), a document containing each of the MbT section headers (such as those found in *Appendix 10. Chapter 6: Monash businessThink (version 7*), pg. 268) and of the MbT metrics as shown in Table 6-1.

6.3.2.1 Feedback on critical thinking metrics

Respondents were asked to briefly critique the metrics and then suggest additional questions that may measure each metric.

The following observations were made:

- ‘Business Sense’ can be assessed through estimating the cost of a particular project as part of project planning. However, this would likely be undertaken by a business manager rather than a graduate
- ‘Business Sense’ is expressed in the workplace by trying to ensure that projects stay within budget
- ‘Business Sense’ is very useful and would require the respondent to potentially provide more than one reasonable response.
- ‘Consideration of Implications’ is expressed in the workplace by defining product specifications
- ‘Considering implications’ is well assessed by considering what the next steps of a process/project are
- ‘Systematicity’ may be expressed during data recording
- The checking of batch sheets (as contained in MbT v1) is reflective of a quality control role and would require the graduate to express ‘systematicity’ and ‘identification of problems’

These findings supported the types of items that we had developed for the MbT and provided ideas for future MbT questions. More findings are presented below.

6.3.2.2 Feedback on scenarios and changes made

On the whole, the feedback from the industry representatives was supportive of the general framing of the MbT questions. Most helpfully they suggested a new type of question that would fit into the MbT metrics. This new question aims to review the production records of a given formulation and compare it to its intended formula. This became Question 12 in the MbT version 7 (*Appendix 10. Chapter 6: Monash businessThink (version 7)*, pg. 268).

While other question types were suggested, those suggestions were deemed to be too subjective in nature or too difficult to implement in a closed-style question. For example, one suggested looked at the idea of pre-project costing as a form of 'business sense'. The respondent proposed allowing the cost of a project to be exceeded 'modestly' and still to be considered an appropriate solution. This idea would fit nicely into 'business sense' however it would be difficult to define 'modestly' in this context without providing the test-taker with an explicit instruction on what constitutes a 'modest cost overrun'. In industry, a graduate would likely have to have such a discussion with their manager to find what is acceptable in their context. Instead, having provided an idea of what is acceptable, the question in the MbT would not be able to assess whether the test-taker understood this idea or was instead being led into using that knowledge. This would then become a trivial costing exercise.

Table 6-5. Summary of industry feedback and changes on the MbT version 1.

Comment	Response
Sections 1-3 are appropriate for grads	No action required.
Sections 4-5 are possibly too advanced for a graduate, instead they would do the ground work and the manager would do the RCA	Still a good introduction to the concepts. Not changed
Section 6 is good for checking specifications of suppliers	No action required.
Could also consider cost-driven questions (pre-production cost estimation)	Too algorithmic, however can be shifted into the formulations question
Could consider a question requiring respondents to build a specification sheet from a range of supplier specification sheets	Very algorithmic and subjective
Could consider finding a cost target, but be allowed to exceed that cost target modestly if required	"Modestly" is too subjective to form into a question. Would require an explicit mention of the allowed excess. The excess would also be company- and context-specific.
Could consider a data recording question (systematicity)	Too algorithmic, cannot form as closed-response
Could consider a question looking at batch sheet and seeing if materials added are correct	Combined into new Q13
Consider question about comparing material sheet with Cert of Analysis from manufacturer	Would be a replicate of the testing schema questions (Sections 1-3)
Consider question to cross check calculations of a colleague	Would be a replicate of Section 6
Typically colleagues will cross-check each other's work in a contract manufacturing setting	No action required.
Consider question checking batch sheet (QC job)	Combined into new Q13
Consider question on converting %w/w to actual mass	Combined into new Q13
Consider question around amount added vs amount needed; calculate and compare QC results	Combined into new Q13
May not be appropriate to review a colleague's data	All other companies had no issues. Not changed.
Business Sense is good, incl. provision of 1+ solutions	No action required.

6.3.2.3 Feedback on auxiliary documents and changes made

Feedback on the auxiliary documents focused on having an authentic appearance. Specifically, the formulation document was to include a table specifying the components to be added. The amounts of each component were to be included in both absolute weights and percentage mass (%w/w). This new form brings the document in-line with similar documents in industry.

Table 6-6. Summary of industry feedback and changes on auxiliary documents for MbT version 1.

Comment	Response
Formulation-style (FOR-001) should be more similar to a batch production sheet, containing ingredient and %w/w	Added a batch-sheet style table (ingredients and %w/w) to FOR-001
Right content, different appearance, same headings	No action required.
FOR-001 currently looks more like a lab report, should be more like a batch sheet	Added a batch-sheet style table (ingredients and %w/w) to FOR-001
MSS contain too many variables, consider swapping with an MSDS	All other companies had no issues. Not changed
RES-001 should come as a PDF rather than an email	All other companies had no issues. Not changed
MDS, TES are similar to that in our industry	No action required.
TES are good	No action required.
MDS use different parameters	No action required.
FOR should be as batch sheet	Added a batch-sheet style table (ingredients and %w/w) to FOR-001
Partially-filled MDS is good	No action required.

As a result of these changes, the MbT version 2 was drafted and taken to the next step in validation.

6.3.3 Language expression (MbT version 3)

The faculty employs an education design team to assist in design, development and assessment expertise in educational design. At the time, the lead educational designer had worked with the faculty for a number of years in this role after coming from a teaching position at another tertiary institution. The educational designer was to review the appropriateness of the language and structure of the MbT v2 with a particular focus on lexical and logical ambiguities.

Two education designers (including the lead education designer) were provided with a paper version of the MbT v2 and asked to consider the MbT in its entirety and to suggest improvements to the structure and language used. They were asked to assume that the CT metrics were valid. Of greatest concern to the MbT author was any use of language that may not be accessible to students from non-English-speaking backgrounds.

Table 6-7. Summary of feedback and changes for the MbT version 2.

Comment	Response
Test introduction requires more 'padding'; introduce it as a test and provide some background context/purpose of the test	Updated
For each section header, place the aux docs references AFTER the intro text so that students read the section header before searching and reading aux docs	Updated
For each section header, provide more background about the company/division so that naïve students are given some concrete context in which the questions sit, rather than abstract concepts	Updated
For all sentences/questions, consider what other interpretations can be made (be careful of verb choice)	Checked
Explain the role that the respondent is 'filling' in each department	Updated
Tweak the terminology and linguistic choices; check implications of verb choices	Updated
SS1 picture, include the word 'identify'	Updated
For all SS place 'hints' into image where possible	Updated
For some questions, consider providing an example	Updated
For questions looking at 'least' and 'cheapest' consider a sub question asking respondent to state the qty or costs of test so as to reinforce the focus of the question	Updated
In SS1 consider repeating of the table (Qn1) throughout all those subsequent questions as a tool that students can use	Q3 & 4 updated
Consider providing more background on what 'products' the respondents are finding so to reduce the level of abstraction required	Updated
Qn6/7 check wording	Checked
Qn9 include a sentence that will clearly differentiate it from the above question	Became Qn10. Updated
Consider separate context for SS3 (formulation testing) to differentiate it from SS1 (ingredient testing) so that misunderstandings from SS1 aren't carried over	I think these will be sufficiently distinguished in the Section intros.
Before PFD question, consider providing an example of PFD reading and/or a question to test their reading of the PFD so that can assess whether respondent can/cannot read PFD rather than not being able to do the CT	Provided explanation of how to read.
In estimation of question timing, allow approx. 10min per question to allow for document re-reading	Ok
Last SS, define 'short term'	Updated
Reduce instances of the word “that”; rewrite sentences	Updated (45 -> 30)

The feedback from the educational designer focused on improving clarity and ease-of-access for the test. As can be seen from Table 6-7, the major portion of adjusting the MbT involved providing more context to the respondent so as to reduce the level of abstraction required leading to reduced mental load and minimised impact on test-taking motivation (Schnotz, Fries, & Horz, 2009). It was originally envisaged that the questions were to be non-specific. This was intended to allow the student to recognise that there was no prior knowledge needed to undertake the MbT. However, it became apparent that this lack of specificity instead may have encouraged the students to speculate about the subject of the questions. They may speculate that the products being abstractly discussed were perhaps a pharmaceutical powder or some other ingredient that with which they have had prior experience. This would lead to external information then being brought to bear on these questions.

The main adjustments in this regard included: providing a background context through the use of introductory headers at the beginning of each paragraph; providing key points or hints in the form of diagrams within each section header; and reinforcement of questions through the use of clarifying sub-questions (*e.g.* for a question asking the respondent to determine which tests are lowest cost, follow-up with a question asking them what the determined lowest cost is). These fixes were fundamental changes that carried over to the final version. By redrafting the test introduction and the section introductions, we were able to remove some of the abstraction required. By introducing more detail around the fictitious company and the student's role, perhaps there is a greater degree of industry context alignment.

6.3.4 Development of closed-end questions for pre-pilot testing (MbT versions 4 and 5)

MbT v4 represented the first version that would go on to pre-pilot testing. It contained all the previous updates. However, it contained three open-ended versions of questions from MbT v3. One aspect of CT was difficult to replicate was allowing respondents to justify their responses. In particular, MbT Section 6 looks at a problem during the production of a product. This section aimed to probe the student's ability to identify potential causes of the problem and then speculate about potential solutions before considering the viability of these solutions. Pilot versions of the MbT contained open-response versions of these questions. The open-response nature allowed for the pilot group students to suggest their own potential cause, solutions, and justifications. These options, combined with our own, then formed the closed-response versions of these questions in MbT v7.

6.3.4.1 Initial Think-Aloud/Pre-pilot testing

An initial ‘think aloud’ session as conducted with six self-selecting BPharmSc third-year students at the end of 2017. These students were recruited through advertising during lectures. Our initial intention was to conduct multiple think aloud sessions, however small student recruitment necessitated that we only conduct a single session.

The intention of this session was to have students work through as many questions as possible in 90 minutes. Meanwhile they were to ‘speak aloud’ their thinking process. To enable free-flow of ideas, the primary researcher facilitated this session. The facilitator introduced the MbT by outlining the background and rationale of the test. Students were instructed to work through the MbT in a single group while vocalising their thought processes. They were reminded that the facilitator would not intervene to assist with responding to the MbT but could provide clarity if required and may interject to ask students to further explain their thought processes. This session was audio recorded and handwritten notes taken. The audio recording was only utilised to supplement the handwritten notes and so no transcription was made.

This exercise uitilised the MbT v4 which comprised two documents, the test booklet and the handouts booklet. The test booklet contains all the sections and then refers to particular documents within the handouts booklet. The handouts booklet contains all the auxiliary documents in numerical order.

In the think-aloud session it became apparent that the students would begin by reading the section introduction which then tells them which auxiliary documents are required for that section. They would then take those documents from the handout booklet and read through them thoroughly, often noting, circling or highlighting particular information. When they were prompted, one student explained that they were ‘finding relevant information’, even though they had not yet read the question. This process took an extraordinary amount of time, until they were encouraged to continue to read the questions.

Students then attempted the first question, which required them to identify which of the available test schemas will collect the missing information. One of the students was explaining aloud that they will use the name of the test as the basis of whether or not it seems like it would collect the required information. This is definitely not the intended process as the test item introduction outlined what part of each test schema is relevant.

Based on the extremely slow work speed and the inefficient approach to reading the auxiliary documents, later versions of the MbT contain the following improvements:

- The auxiliary documents are split into a smaller bundle that is relevant only for that given section. Auxiliary documents can exist in multiple sections where required,
- Section introductions remove reference to specific documents. This instead is replaced by the section-specific bundle of documents,
- MbT Section 1 introduction was changed to tell students to "*Carefully read **Section 1** and **Section 2** of each test protocol (TES-001 – TES-009)*" with the intention of highlighting the relevance of those sections. This may not be a true reflection of what would happen in industry. We do believe that this compromises the authenticity of how a graduate would approach such a problem in industry, but it is a compromise between authenticity and time taken to answer the question. Further, this hint would be reflective of an experienced work mentor pointing out a shortcut to a new graduate.

These new changes were incorporated into MbT v5. The MbT v5 also includes simplifying language and removal of other ambiguities. As the students were not able to complete the MbT within a sufficient time-frame, a separate pilot study was then to be conducted, using the MbT v6.

6.3.5 MbT review and restructure (MbT versions 6 and 7)

MbT v6 is the first instance of the instrument being named as *businessThink*. This version was the last paper-based form of the MbT. As will be seen through this section, there is little substantial change to the structure and content between MbT v6 and MbT v7. The MbT v7 can be found in Appendix 10.10.

6.3.5.1 MbT Student Feedback

Prior to any further testing, the MbT v6 was administered to a single student who was working with our research group over the summer of 2017/18. She was provided a paper-form of the test and handouts and instructed to complete the test in her own time, at her own pace, without the help of others. She completed the MbT sequentially over four days, on campus. She was asked to give feedback on each of the questions and to estimate how long it took her to complete each question. For our purposes, her actual answers were not as important as her perceptions and feedback on the questions. This was a non-representative sample, however her feedback around ambiguities were enlightening and are reproduced on the next pages.

Table 6-8. MbT v6 pre-pilot testing feedback

Comment
Section 1 Choosing tests to collect missing data, based on the quickest series of tests or the cheapest series of tests. Q1: *Do you need the equipment for the entire duration of the procedure or only the amount of time it has a specified use as per the procedure* Q2: *"<1min* [duration]*": confusing, is it negligible? can you spend the 30min block doing something else or do you need to dedicate the 30min block to it* *Especially confusing if equipment is needed in the <1min, make sure it is free to be booked? etc*
Section 2 Comparing four samples of the same ingredient and deciding which is the best, which is the worst, and on what criteria the decision was made. *This section confused me, when it said to rate the sample most preferred I thought that all the factors had to be taken into account; time consuming* *Could be my fault: I did not read through the entire section for this and instead just started on Q5* Q7: *The wording confused me: 'which data was most important in your decision to NOT choose that sample'* *Personally, I chose it because it performed the least well on the three reasons why I chose my most PREFERRED sample, so when you say choose 3 reasons, are you looking for 3 reasons where sample performed the most poorly or three reasons where the sample performed very WELL but those reasons are the least valued out of all the reasons*
Section 3 Schedule a series of tests and determine the costs required to run those tests (including material costs, running costs). Q11: *Slightly confusing for how to figure out the preparation and testing costs as that would've required Handout #5.1 and the question did not say 5.1 as one of the handouts needed to answer the question, it just took a bit more time flipping through the Section 3 material to find it* Q12: *If there are two 30min blocks, can you pause between the two?* *Can you continue between days e.g. follow on from end of Tuesday to Wed morning*
Section 4 Review a production sheet and identify if any errors have been made. Q13: *When it says batches of FOR001 produced after 2am, do you mean batches that STARTED production AFTER 2AM or can batches that started production at 1:47 and concluded at 2:55AM be included?*

Comment
Section 5 No issues reported.
Section 6 Troubleshoot a production issue where a produced batch of product has not passed quality control testing. *Was confused as I did not know the importance or the function of the scent of the product and hence it was especially hard to come up with solutions to this problem*
Section 7 Identify potential errors between reported results, and recorded data. Identify potential causes of these errors. Q19: *This one was confusing for me as there were technically two reference sheets and to see which one was the 'correct' one and which one had the copying errors needed an identification of the dates that they were produced and if this is not done then your results would be the wrong way around* *MDS-005 also being the STANDARD confused me in the beginning* Q20: *Determining the difference between a HUMAN and a MACHINE error took time* *My original assumption was that if ALL the results from one procedure was wrong, then it would be a machine error but if only one or two were wrong then it would be a human error. This was later found to be wrong as apparently if something is within the range specified in the Handout #4.1 which was also NOT in the list of handouts that you needed to answer the question* *I found that to be able to do these questions correctly I HAD to read through the entire section before starting the question as reading the rest of the questions in that section determines the method and approach I would use for the first question and onwards* *For quite a few sections e.g. Section 2 there was quite a lot of flipping back and forth between reference pages and the ones that I am comparing to which got too annoying so I ripped out a few reference pages e.g. #4.1*

6.3.5.2 Further student feedback

The MbT v6 was also administered to 10 students from the Bachelors of Engineering/Pharmaceutical Science (n = 4), Pharmaceutical Science (n = 2), and Medical Science (n = 4). These students were recruited through social media channels and were all either students of the research team members, or peers of our summer student. Students were self-selecting and completed the test for no credit. These students were provided a PDF version of the MbT v6 with digitally fillable fields to provide responses. The students were also asked to take notes on how long they took to complete each question, and to provide feedback on any difficulties they encountered. Students completed the MbT off-campus over 4–5 days.

The verbatim responses are not provided due to space limitations, however the changes that were made to the MbT v6 are noted below. Student feedback focussed strongly on clarification of item wording and removal of ambiguous language.

Table 6-9. Summary of changes to MbT v6 following pre-pilot testing.

Describe the change	**Justification**
Question 11; rewording of response section to include FOR-001 and TES-008 more prominently	Clarity
Question 12; return wording to original of 'were being produced after 2:30 AM': deliberate ambiguity	Specifics of question
Q12; remove underline of 'after'	Not necessary
Q13; add statement for contamination not occurring in pipes: "The contamination is not coming from any of the pipes"	Clarity
Updated handouts 1, 2, 3, 7	Clarity, corrections
TES-005 section 5, step 5.17 updated step numbers	Clarity
TES-009 Step 5.1 updated to reflect only 50g required	Consistency
Update TES-00x & FOR-001 to indicate pause time in procedures as being after bench / before testing / other as req (check w/ answer schema)	Clarity
Answer schema for all booking questions updated with new pause times in each TES	No changes required
TES-00x Section 3 updated as follows: S 3.1 now read: "This test will take the following duration over two phases", S 3.2 (NEW): "This test requires: 50 grams of material for the preparation phase which will also be used in the testing phase.", and S 3.3 (old 3.2): remove material requirement	Clarity
Section 2 intro updated to indicate that all information is provided in handouts.	Clarity
PFD-001 updated labels to have Base Reactor 2 renamed as such	Clarity
PFD-001 arrow #8 adjusted to remove potential misunderstanding about 'no material travel between base mixers'	Clarity
PFD-001 updated legend to include 'Process' such that contamination can only come from a process, as stated in Section 5 header	Clarity
Section 6 header updated to refer to 'the cause of the problem'	Clarity
Q15, Q16 updated to talk about 'causes of the problem'	Clarity
BAT-001: updated total mass added	Clarity
BAT-001: updated values to ensure that batches are within spec as appropriate. Percentages are based on total mass. Total mass is given by the sum of all the masses added. Respondents should not rely on the 'total mass added (kg)' entry as this is imprecise for all batches and deliberately wrong for Batch 7.	Correction
Altered S5 Q14 'Select from Col1|Col2' graphic to have vertical dashed border	Clarity

Describe the change	Justification
Updated SS6 intro text to indicate that later batches have not been affected, and to reinforce the product's putrid smell	Clarity
SS6 Q15, 16; update to be MCQ-style (classify each as viable/inviable	Digitisation
SS6, remove Q17 (now irrelevant and bundled into Q15/16). Rename Q18 -> Q17 / Q19 -> Q18	Not necessary

The answers were also revised based on inconsistencies. Lastly the MbT v6 was transferred to the online platform *Qualtrics* for any future administration. This updated test became the MbT v7. The MbT v7 was then used to undertake a larger set of validation and reliability studies.

6.3.5.3 Cognitive Processing

In lieu of the results of the 'think aloud' session (see Section 6.3.4.1), the responses from these students (the individual student in Section 6.3.5.1, and the 10 students in Section 6.3.5.2) provide some insight into the degree of cognitive processing that may have occurred. For this process we are looking for instances where the student has demonstrated one or more of the industry-aligned CT metrics (see Chapter 3): *systematicity*, *business-sense*, *multiple solutions*, *consideration of implications*, and *identification/awareness*.

Systematicity: Of the 10 students, two appear to have taken systematic approaches to answer questions from Section 1. Section 1 lends itself to systematicity by asking respondents to find optimised solutions. Written notes from both students appear to have utilised a brute-force method (*i.e.* trying every combination sequentially) to find an optimal solution. In this scenario this would be an appropriate approach as a brute-force method can be conducted very quickly using technology.

Business-sense: the individual student is starting to show sign of business awareness in her comments around Question 12. It would appear that she is considering the business reality around running work across multiple days.

Multiple solutions: as no student provided full notes detailing their thinking processes, it was impossible to identify any instances where they appeared to be deliberating between two or more appropriate solutions. Ideally a respondent would strongly consider several solutions and weigh up the costs and benefits of each.

Consideration of implications: in response to Question 20 (which is now Question 18 in the MbT v7), the individual student appears to be working through the implications of her interpretation of the question and how that affects her choice of answer. This is the intention of this question.

Identification/awareness: Again, without verbatim notes there is no clear indication that this metric was addressed directly.

Overall, however, most the responses focus on ambiguities. This is unsurprising as this was the original intention of this part of the drafting process. Notwithstanding, some elements of cognitive processing are evident that align closely with the industry-align CT metrics.

Postface

This chapter looked at the process for developing the MbT, including the initial validation studies and subsequent changes. The next chapter looks closer at the statistical approaches to formal validation of the MbT.

Chapter 7

Validating a Novel Critical Thinking Assessment

Preface

This chapter covers exactly what it says on the box; we are statistically validating the MbT.

Chapter Contents

This chapter is under consideration for publication in a peer-reviewed journal.

The manuscript is reproduced in full below with minor editing of layout and formatting for consistency. Reference list and any appendices are reproduced in the dissertation end matter.

The MbT: towards an industry-aligned assessment of critical thinking skills in STEM.

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Abstract

Critical thinking (CT) is widely seen as a key competency for university graduates to have mastered before entering the workforce. However, a plethora of CT definitions has led to a range of generalised CT assessment tools. We build on previous work uniquely conceptualising CT as a set of industry-aligned skills derived directly from potential future employers. This paper presents a novel approach to digital assessment of these industry CT skills, called the Monash businessThink (MbT). We present the guiding CT framework, the MbT structure, the unique and generalisable item and response generation, including approaches and encountered difficulties, and the method for validating the MbT. A pilot study of 99 students from an Australian institution provided preliminary validation evidence. MbT scores were found to correlate reasonably with university grade point average (GPA) and displayed an acceptable lack of correlation with domestic/international status and first-in-family status. Internal validity and reliability studies highlighted multiple assessment items needing review. Positively, both statistical data and respondent feedback support the notion that the MbT appropriately reflects the industry context. There are indications that this improvement over generalised CT assessments lead to greater test-taker motivation.

7.1 Introduction

Critical thinking (CT) has increasingly become part of university syllabuses. For those graduating university, there has been an increased demand for effective CT skills to be demonstrated in a workplace environment (American Management Association, 2012; Bourn, 2018; Husain, Mokhtar, Ahmad, & Mustapha, 2010, p. 432; Matthews, 2017; McCadden & Brown, 2014; Pearl, Rayner, Larson, & Orlando, 2018). Specifically, in the Australian context, a survey of employers found that those who are professional, scientific, and technical services sectors had a very strong desire for CT skills in STEM-qualified graduates (Prinsley & Baranyai, 2015). One clear difficulty in teaching CT is in conceptualising and then operationalising CT. A core issue in this area is the lack of clear-cut operational definition of CT and a plethora of debated definitions (see Liu, Frankel, and Roohr (2014) for an extended review).

7.1.1 Existing critical thinking frameworks

There is a large corpus theorising on the nature of CT. Reflecting back on Section 1.2, we can recall that CT is seen as a higher level of thinking; more than just thought (Ennis, 2015) and may be considered as a 'purposeful act' (Halpern, 1998) of 'reasonable and reflective thinking' (Ennis, 1993).At this point it is worthwhile to recall the discussion around the context-specific nature of CT (see Section 1.4) and the debate on whether CT is a generalisable skill. The main points of that discussion indicated that skills transfer (and CT transfer) between domains can be limited when it is not taught using scenarios/assessments that reflect the domain in which one is to utilise their CT skills. We can then recall the work of Lund (1997) in identifying seven areas of focus for authentic assessment: realism, unstructured problems, complex activities, feedback, multiple perspectives, collaboration, and cross-domain thinking (see Section 1.6.3). Taking these approaches and the findings around how industries conceptualise CT (see Chapter 3), we now move to look at how a valid and reliable assessment of CT may be created.

7.1.2 The Monash businessThink operational definition

Building on the recommendations of Liu *et al*. (2014) regarding the design of a valid CT assessment, the authors created a bespoke tool to quantify CT skills development in their undergraduate pharmaceutical science course in an Australian university. This tool became the Monash businessThink (MbT) tool. The process used to develop this tool is intended to be generalisable across other science, technology, engineering, mathematics, and medicine (STEMM) disciplines. Uniquely this tool does not rely solely on contested CT definitions but instead builds on the expertise of "domain experts, assessment developers, … institutions, and faculty members" Liu *et al*. (2014, p. 19) to arrive at an industry-aligned tool to assess CT. The authors have previously investigated how industries in our workplace environment conceptualise and discuss CT (Pearl, Rayner, Larson, & Orlando, 2018) (see Section 3.4.2). This paper arrives at five key industry-aligned CT metrics: *thinking systematically*, *having strong business-sense*, *considering multiple* *viable solutions*, *considering the implications of decisions*, and *identifying potential problems and solutions*.

7.1.3 The Monash businessThink design considerations and core features

7.1.3.1 Review of currently available critical thinking assessments

Before drafting a new tool, it was appropriate to review as many currently-available tests of CT as possible. The purpose of this review was twofold: (i) to identify any tests that also assess similar conceptualisation of CT, and (ii) to compare the modalities of various tests (*e.g.* essay-style response, short-answer, closed-answer). We conducted an unpublished literature review and web search which identified 76 potential tests of CT. Of these, 29 were excluded; ten were aimed at children and/or high school students, seven were not available, six were not assessments as such but instead were variously courses or assessment rubrics, four could not be further located, and two were stated as adaptations of otherwise available CT tests. The remaining 47 tests were reviewed against the above stated purposes. We do not present the full review methodology and discussion here, but our findings indicate that no current test assesses the same areas as the MbT and most utilise close-response questioning. The few assessments that incorporate an open-response portion are marked by assessors trained by the test publisher.

7.1.3.2 Structure

The MbT is a semi-realistic representation of work in industry. Based on the feedback from industry partners, the MbT test-taker takes on the role of a recent graduate in fictitious company making an unspecified consumer good. This is similar to roles that our graduates genuinely have undertaken, and will continue to undertake. From discussion and experience with industries, it is clear that CT does not occur in isolation but instead requires input from others' expertise and company documents. As such the MbT is comprised of two main parts; the *tasks*, and the *auxiliary documents*; respectively a series of industry vignettes each centring on a problem or issue which your manager presents, and the extra workplace documents needed to be synthesised to respond to the task.

In total there are seven tasks that contain one or more individual assessment items. The auxiliary documents are based on real-world documents and include, amongst others, material data sheets, formulation recipes, and batch records. Prior feedback from industry partners indicates that these documents have an acceptable degree of face validity, that is, they look like real documents.

From the outset we intended that the MbT can be completed in a single one-hour session so that it can be easily incorporated into current classes. With large cohorts in our courses, we desired to have the tool be automatically marked. This required us to administer the MbT digitally and limited the types of responses that we could collect and assess. In using a digital platform however, respondents better emulate the working style of industry, further increasing the contextual validity of the MbT.

7.1.3.3 Item Context

Content for assessment instrument was drawn from dedicated industry scenario(s), and pre-existing discussions taken from the industry semi-structured interviews.

As indicated by Yin (2018), case studies are an appropriate option to investigate "a contemporary phenomenon … within its real-world context". For the purposes of this research, students' engagement and use of CT within the industry context lends itself nearly to Yin's use of case studies as a research tool. To this end, the instrument questions were informed by a series of scenarios that were drawn directly from industry. These scenarios were collected using a modified approach outlined by Yin (2018), as detailed in the following sections. These scenarios were taken from experiences of problems that graduates can be expected to encounter in companies that hire graduates from our course. Having been drawn directly from industry, the questions derived from the scenarios are intended to approximate the experience that a graduate can expect to encounter in the workplace. This data was collected using semi-structured interviews with industry representatives (Pearl, Rayner, Larson, & Orlando, 2018) (see Chapter 3). These examples of CT in industry were developed into a series of tasks and items for the MbT.

7.1.3.4 Item format

Previous research in this area has highlighted the limitations of using closed-response style questions in assessing CT, whereas open-response questions allow the respondent to fully develop and explain their reasoning (Ku, 2009; Scouller, 1998; Stanger-Hall, 2012).

There are multiple examples of multiple-choice question (MCQ) based CT assessments including commercially available and bespoke tools. One such bespoke tool is described by Morrison and Free (2001) in assessing undergraduate nurse student CT skills. While

Morrison and Free clearly articulate the cost and time benefits of MCQ CT assessments, their shift towards eliciting CT is through asking respondents to select the 'most important' or 'greatest implication'. It is limited in having potentially subjective responses. Morrison and Free describe having all responses as being plausible or "relatively possible", but one option being "better than the others" Morrison and Free (2001, p. 20). Considering the potential complexity of healthcare situations, what one person considers 'most important' may be 'second-most important' to another. The respondent has no ability to explain their reasoning behind choosing or disregarding certain options (Ku, 2009). In summative assessments, without the ability to justify or clarify one's response, the respondent defaults to the 'expected answer'. Additionally, the assessor implicitly assumes that the respondents are all following the assessor's logic. One remedy to this is either all plausible options appear at the outset to be equal (and therefore difficult to discriminate between), or one stands clearly above the others (and therefore enables respondents to 'game' the assessment).

From a general assessment perspective, Scouller (1998) identified essay-style questions with requiring students to engage in deeper level thinking when compared to multiple-choice style questions. Similar to the findings by Liu *et al*. (2014), only a minority of the 47 commercially-available CT tests studied in this report utilise an open-response format (n = 11) (either standalone, or in combination with closed-response options). This style of response may lack face validity (Liu *et al*., 2014). While some researchers argue in favour of open-response formats especially in authentic assessments whilst acknowledging the potential for subjectivity in scoring (essay-style, for example) (see Ashford-Rowe, Herrington, and Brown (2013); Eubanks (2009); Stein and Haynes (2011)), others also argue for the pragmatism of closed-response formats (Downing, 2006; Ennis, 2008; Haladyna & Rodriguez, 2013). Proponents of closed-response format highlight the ease of administration to groups as a primary consideration. Critics of this approach note the difficulty in assessing the thought process of the respondent (Norris, 1989). Other criticisms levelled at closed-response formats are the possibility of 'gaming the test' by which highly able students are able to deduce clues to the correct response and in doing so reduce the pool of options from which they need to select. However, the use of well-written questions and responses reduces this possibility (Downing, 2006; Haladyna &

Rodriguez, 2013). Complaints that respondents could simply guess the correct response are statistically fallacious. For example, with a minimal increase in plausible distractors, the expected 'score' from guessing decreases significantly.

While the essay-style approach appeared to lend itself more appropriately to assessing CT skills, the convenience moreover, low running cost of a multiple-choice-style test was taken as the more pragmatic choice.

7.1.3.5 Response Generation

To alleviate the risks of respondents 'gaming the test', the MbT utilises closed-response questions with a very large set of potential solutions. For example, one task requires the respondent to indicate which laboratory tests (if any) they would conduct to collect a prescribed set of data. Of the nine available tests, the respondent can choose from zero to all nine tests and any combinations therein. As the order of tests is unimportant, there are 512 combinations. A simple approach to generating these solutions would involve using any common spreadsheet editor to generate all possible solutions and then to highlight or select the optimal option. Of all the options, one or more is mathematically optimal and would receive full marks. If desired, the next near-optimal solutions can be given partial marks. With a large number of potential solutions, the respondent is required to engage with the material rather than guessing a solution. Ideally the respondent may utilise problem-solving or CT techniques to approach this question in a systematic, rather than one-at-a-time 'brute-force' manner. Issues around having the respondents justify responses is negated through question design. Most tasks require respondents to find optimised solutions (*e.g.* optimum scheduling, cost, *etc*.) however sub-optimum solutions are still partially scored. This style of tasks does not need justification as their responses are mathematically proven optimal or sub-optimal. Nevertheless, of the seven tasks in the MbT, the final two tasks ask respondents to identify a potential cause of a problem and then suggest viable remedies. The first part of these tasks assesses whether the potential cause is a *possible* cause (not necessarily *probable* cause). The second part then assesses whether the chosen remedies will address the selected cause.

7.1.4 Pilot test validation

A pilot test of the MbT was conducted in early 2018 using students undertaking the Bachelor of Pharmaceutical Science (BPharmSc) and the Bachelor of Pharmaceutical

Science / Bachelor of Engineering (BPharmSc/BE) with students covering three years of the course. In conducting these validation exercises, we follow the approach given by Downing and Haladyna (2006).

From the pilot study data, we validated the MbT by addressing four research questions;

1. How are the scores of the MbT related to other CT assessment measures?
2. How are the scores related to other non-CT measures, such as year level, university grade point average (GPA), domestic/international status, and self-reported first-in-family to attend university (FIF)?
3. How valid is the MbT regarding test-retest scoring consistency?
4. How internally reliable are the individual assessment items of the MbT in their ability to score in a consistent manner?

7.1.5 Sample group

The MbT v7 was administered digitally using the Qualtrics platform. Respondents were encouraged to use any technology they desired to assist in responding to the items. The pilot study was attempted by 99 participants. Students were recruited using advertising during lectures. These students were self-selecting and come from the Bachelor of Pharmaceutical Science (BPharmSc) (n = 69) and the Bachelor of Pharmaceutical Science / Bachelor of Engineering (BPharmSc /BE) (n = 27) studying in first- (n = 9), second- (n = 14), and third-year (n = 73) of their course with missing data for three respondents. For this study, two groups of students were required; (i) the full cohort to complete the test once and whose demographics data was collected (n = 99, all the participants), and (ii) a subset group (n = 15) attempted the MbT twice and a separate CT assessment. The main cohort provided data for the relations to other variables (divergent validity), internal reliability, and internal validity. The subgroup provided additional data for the relations to other CT measurement (convergent validity), and test-retest scoring consistency.

All students undertook the MbT once during semester in early 2018. The subset cohort then completed a separate CT assessment after three weeks, and a follow-up MbT after a further three weeks. Demographic data was collected after end of semester examination period. In all instances, students completed the MbT for no credit.

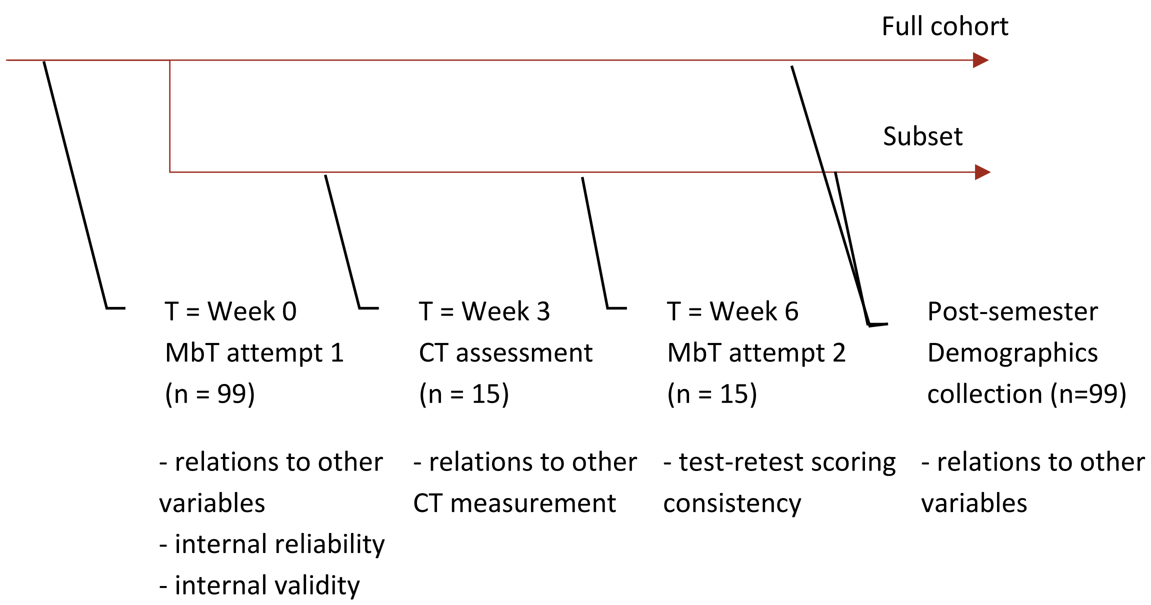

Figure 7-1. Schematic of testing procedure and data collection.

This research was conducted with the approval of the institution's human research ethics committee. In all instances, the MbT was attempted on-campus in electronic format in an exam-style session invigilated by one of the researchers. As each of the seven sections of the MbT are independent, students were randomly assigned to one of three groups which attempted the MbT beginning at Section 1, 3, or 6 and then continuing sequentially. Demographic data was collected at the end of the semester after the release of results for that semester. All tests were conducted for no credit nor any other inducement.

7.2 Method

7.2.1 Relations to other critical thinking measurement

If the MbT is measuring the same construct as other CT assessments, then respondents should score similarly between CT tests. This study utilised the California Critical Thinking Skills Test – Numeracy (CCTST-N). Although our previous work has indicated that the CCTST-N may not accurately measure CT skills in our context, the large body of extant literature that utilises the CCTST-N leads us to view this as still the best option for this validation exercise. Cost and time constraints also prevented us from utilising other tests as a supplementary source of validation data.

The CCTST-N is designed to measure CT skills in undergraduate and graduate students (Insight Assessment, 2015b). It measures cognitive skills of *analysis*, *interpretation*, *inference*, *evaluation*, *explanation*, *induction*, *deduction*, and *numeracy*. It is a standardised, 40-item, timed, multiple-choice test. Its Kuder-Richardson value for the *overall* CCTST-N score exceeds .70 (Insight Assessment, 2015b). In our communications with the CCTST-N publisher, we were assured that this test, while developed for US students, is applicable and appropriate for use in an Australian STEMM context (*personal communication*).

A subset of the participants (n = 14, third-year students) who undertook the MbT then completed the CCTST-N under exam-style conditions in a session invigilated by one of the researchers. The CCTST-N was completed three weeks after the initial MbT. The overall result from the CCTST-N is compared to each MbT section result using Spearman's rank order correlation (Spearman's rho) and determining effect size as per Cohen (1988).

7.2.2 Relations to other variables

In validating this test, we must ensure that we are measuring CT ability rather than other unrelated traits. Previous research has shown positive correlations between CT ability and year-level (so-called *maturation effect*) or CT instruction throughout a course of study (El Hassan & Madhum, 2007), and GPA (Cox, Persky, & Blalock, 2013; Liu, Mao, Frankel, & Xu, 2016) (perhaps indicating stronger CT ability leading to better academic outcomes). Conversely research has indicated negative correlations between CT ability and English language proficiency (El Hassan & Madhum, 2007; Rashid & Hashim, 2008), indicating potential language comprehension difficulties.

Additionally, we consider students who are self-identified as *first-in-family* university attendees (FIF). These students, otherwise known as first-generation attendees, tend to have lower academic achievement than their non-FIF peers (Ramos-Sánchez & Nichols, 2007) and this may associate with CT ability.

To ensure that the MbT was appropriately aimed at university-level students, the two parts of the MbT (the tasks, and the auxiliary documents) were subjected to the Flesch-Kincaid Grade-Level test (Kincaid, Fishburne, Rogers, & Chissom, 1975). This test was chosen for its ease-of-use and availability. National Health and Medical Research Council (2000, p. 36) and Klare (1963) suggest that a grade-level of 7–11 is appropriate for use in a university-level setting.

To explore the extent to which the MbT related to other measures, we investigated the relationship between MbT total score and participant year level, university GPA, domestic/international status (as a crude proxy for English language proficiency), and first-in-family (FIF) status. Spearman rho correlation was calculated for participant year level, and separate t-tests were conducted for each of: university GPA, domestic/international status, and FIF status. Results of the Flesch-Kincaid Grade-Level test of readability is also reported.

7.2.3 Test-retest scoring consistency

The subset group of respondents undertook the MbT a second time after completing the CCTST-N. Kline (2005, pp. 168-171) indicates that if an assessment is repeated, assuming no changes in the respondent, then a similar score will be obtained over two independent sittings. This test-retest reliability study was conducted over a short timeframe of six-weeks. We expect that respondents have not appreciably developed CT skills and so should score similarly in both instances. The results from the test and retest was compared using the Wilcoxon signed rank test with a statistical significance level of $p < .05$.

7.2.4 Internal reliability

The internal reliability measures the consistency between assessment items in measuring the same construct or concept. The internal reliability is measured by Cronbach's alpha where a value greater than 0.7 is considered satisfactory for a low-stakes assessment such as the MbT (DeVellis, 2012, p. 109), indicating that the items are measuring the same construct or concept.

7.2.5 Internal validity (sensitivity)

As discussed in Section 6.1.1.2, we utilise an item response theory (IRT) model for assessing the validity of each item. IRT posits that the probability of a person correctly responding to an assessment item is a function of both the latent skill of that person and the difficulty of that item (Steinberg & Thissen, 2013, p. 337). Using IRT we will be able to determine each item's relative difficulty. Each item can be expressed as an 'item characteristic curve', an S-shaped curve indicating the cumulative proportion of respondents correctly answering the item. The horizontal scale indicates the relative difficulty of the item.

Implicit in this form of IRT analysis is the need to convert responses to a dichotomous scale ('right', 'wrong'). Polytomous responses were converted to dichotomous responses as each item has only one best response. While future versions may utilise polytomous responses to allow for crediting partial answers, this initial analysis uses the dichotomous form for simplicity.

A full IRT model reports three key characteristics for each question; (i) the *difficulty* of each item (the 50-50 cut off point on the horizontal scale, where half the respondents are expected to get the answer correct), (ii) the *discriminability* of each item (the steepness of the S-curve at the 50/50 cut off point, the magnitude of which indicates the strength of relationship between the respondent's latent skill and the discriminability of the item, and (iii) the *guessing parameter* (an indication of the probability of a respondent guessing the answer correctly) (Steinberg & Thissen, 2013, p. 337).

Desirable values for each parameter are; (i) *difficulty* should be spread evenly along the horizontal scale indicating a spread of item difficulty typically ranging between -3 and +3, and acceptable between -4 and +4 (Baker & Kim, 2017, p. 18), (ii) a *discriminability* of at least +1 where a negative value is undesirable as it indicates that higher latent ability correlates with lower correct responses (*i.e.* 'better students' are more likely to answer incorrectly) (Baker & Kim, 2017, p. 26), and (iii) a *guessing parameter* of approximately zero, indicating a very low likelihood of correct guessing of the answer (Steinberg & Thissen, 2013, p. 337).

A full IRT model allows for one-, two- and three-parameter analysis which differ in whether they calculate one, two, or all three of the above parameters. We opt for the two-parameter model which does not calculate the *guessing parameter*. The MbT items are designed deliberately to prevent guessing of responses, as noted previously, and so taken to be negligible. In our IRT model we must utilise dichotomous responses (*i.e.* each item is right/wrong), however, we choose a unidimensional model (*i.e.* the only latent skill we measure is CT).

7.3 Results and discussion

7.3.1 Relations to other critical thinking measurement

For the purposes of comparing the MbT results with the CCTST-N results, each MbT section was considered individually. This would allow the ability to consider the validity of each section individually, and to address issues around students only completing some sections of the MbT. For each section of the MbT, the section scores of the students who completed that section are correlated against the CCTST-N overall score, as shown in Table 7-1. For example, those students who completed MbT Section 1 had their Section 1 scores correlated against the overall CCTST-N scores (*i.e. row 1:* M = 58.5, DS = 27.2). The average CCTST-N overall scores were M = 79.7, SD = 7.3.

As the CT frameworks of the CCTST-N and the MbT differ considerably, we would expect a non-concordance of results between the two assessments.

Table 7-1. Spearman correlations between each MbT section total score (out of 100) and overall CCTST-N results (out of 100) (M = 79.7, SD = 7.3).

		MbT		**Spearman**	
	N	***M***	**SD**	**Sig.**	$\boldsymbol{\eta^2}$
Section 1	12	58.5	27.2	0.41	0.26
Section 2	13	8.5	9.7	0.17	0.40
Section 3	11	23.8	12.6	0.88	0.05
Section 4	12	69.6	15.2	0.31	0.32
Section 5	12	82.9	12.7	0.54	0.20
Section 6	13	54.7	12.5	0.74	0.10
Section 7	12	41.3	22.9	0.93	0.03

Note that not all respondents completed all sections.

For this small sample size there are no statistically significant correlations between scores on any section and overall score on the CCTST-N. This result may in part be explained by the differences in CT frameworks used. The CCTST-N is designed to assess the CT skills as defined by Facione (1990) which look at the actions: *analysis*; *interpretation*; *inference*; *explanation*; *evaluation*; and *self-regulation*. Deliberately these actions are not cast in any particular context and instead aim to broadly cover CT in multiple domains. The MbT meanwhile is targeted to a particular industry-based domain with its metrics and assessment items being deliberately contextualised to our industries. As discussed later, students responded more positively to the MbT for its apparent clear connection to industry-based work rather than non-contextualised CT skills.

7.3.2 Relations to other variables

The average total scores for each year level are shown in Figure 7-2. There was no statistical correlation between year level and score on the MbT (Spearman correlation, *F*

= -0.01, p = .891). This stands apart from previously cited research indicating a potential *maturation effect*. Considering the nature of the course and its increase of problem-based learning in later years, we would expect to see a similar trend within the MbT scores. Low participation rates in first and second year, and the need for MbT item redesign could be suppressing the expected correlation. The large variability in third year results may in part explained by the variety of industry experiences within that year level. Of the 73 third-year respondents, 53 provided information about work experiences. Of those 51, 16 (31%) had completed an industry-based placement of 12 or more weeks, and 35 (69%) had not. Those who had undertaken an industry placement had a higher score (M = 32.67, S.D. = 14.9) than those without experience (M = 26.68, S.D. = 11.7).

The average total scores for students with different university GPAs, different domestic status, and different first-in-family status are shown in Table 7-2. Students with higher GPA tended to score better on the MbT pilot test. Students with a university GPA greater than or equal to 3.50 significantly outperformed students with a lower GPA (Table 7-2) with the magnitude of the performance difference of 0.37 standard deviations. Domestic status and first-in-family status are not statistically relevant indicators of performance on the MbT. Overall the scores on the MbT appear quite low, when taken as a percentage of the total possible score. In this instance, no partial scores were given. The structure of the MbT asks respondents to determine optimum results (see Appendix 10.10). A perfect score would indicate that the respondent selected all the 'best' results. Low scores may be indicative of: an inappropriate scoring system (does an optimal answer truly reflect the use of CT or is a sub-optimal answer equally as valid?); a poorly designed tool; or a lack of critical thought of the respondents. The results from Section 7.3.1 would normally be used to support or eliminate the latter option. Due to the issues outlined in that section, this is not possible. A proper investigation would require the use of another CT tool.

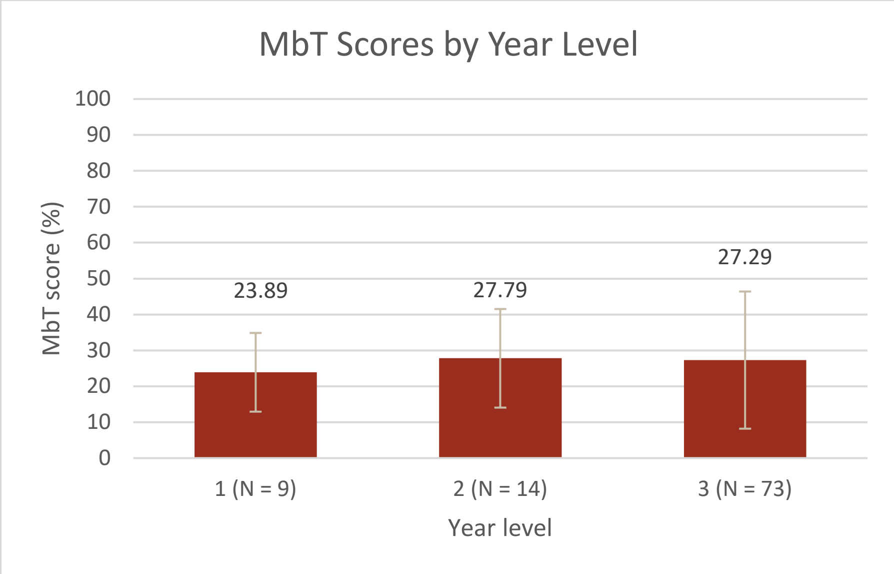

Figure 7-2. MbT scores by year level, with mean indicated and standard deviation error bars.

These results would indicate an expected correlation between academic achievement as measured by GPA and CT ability measured with the MbT. As a proxy for English-language proficiency and university adjustment respectively, neither domestic/international status nor first-in-family status statistically significantly correlated with MbT scores. These indicate a clear coherence of the MbT, avoiding ambiguities and cultural influences, as well as remaining accessible to international and first-in-family respondents.

Table 7-2. MbT total score between-groups analysis for other variables.

Groups	N	%	M	SD	t-test	Effect size
University GPA					2.504*	0.74
>= 3.5	18	18†	35.97	16.23		
< 3.5	59	60	25.72	11.15		
Domicile					0.352	0.21
Domestic	73	74†	28.24	13.37		
International	4	4	25.85	8.94		
First-in-family					-0.057	0.01
FIF	30	30‡	28.01	13.48		
Non-FIF	42	42	28.2	13.77		

* Significance at 0.05 level.

† There is 12% missing data.

‡ There is 18% missing data.

The Flesch-Kincaid Grade-Level Test of Readability indicates that the main body of the MbT has a grade-level equivalence of 7.5, and the auxiliary handouts have a grade-level equivalence of 7.0. These are both within the range of 7–11 suggested by Klare (1963) as being appropriate for use in a university-level setting.

7.3.3 Test-retest scoring consistency

The Wilcoxon Signed-Rank Test provides a statistical indication of the consistency of repeated measures for non-parametric data (Pallant, 2016). Results from the test-retest Wilcoxon Signed-Rank Test are shown in Table 7-3. A significance value greater than .05 is desirable as it indicates that the test and retest scores shown no statistical difference. Several respondents did not complete both the test and retest for some sections.

Table 7-3. Wilcoxon Signed Rank Test for each MbT section

		Test		Retest		Wilcoxon S.R.T.	
	N	***M***	**SD**	***M***	**SD**	***z***	**Sig.**
Section 1	13	0.59	0.27	0.60	0.15	-0.102	0.919
Section 2	14	0.07	0.09	0.06	0.08	-0.552	0.581
Section 3	13	0.26	0.12	0.14	0.09	-2.250*	0.024
Section 4	13	0.70	0.15	0.67	0.14	-0.356	0.722
Section 5	14	0.81	0.13	0.74	0.31	-0.498	0.619
Section 6	15	0.56	0.13	0.49	0.10	-0.670	0.503
Section 7	12	0.39	0.22	0.39	0.23	-0.771	0.440

* Significance at the 0.05 level.

These results show acceptable levels of test-retest validity for all sections except for Section 3. This implies that students are engaging correctly with the questions rather than guessing responses.

7.3.4 Internal reliability

Of the full 18 questions in the MbT, two are excluded from this analysis as their responses are dependent on previous responses and so would necessarily show an inter-relatedness. The calculated total score (using the remaining 16 items) reliability (alpha = .67) shows unsatisfactory reliability (*i.e.* alpha > .70). Four items had showed no variance in responses and were excluded from analysis. Several items are flagged for removal due to low corrected item total correlation (CITC). Questions 11B, and 18 have CITC less than .10. Removal of these questions raises Cronbach's alpha to a satisfactory .71.

The two errant questions, 11B and 18 can be further considered to see why they may not have satisfied the criteria for test-item inter-relatedness. The full Question 11 prompts respondents to plan the preparation of two samples (Q11A) and then schedule testing on both samples (Q11B). The preceding questions of that same MbT Section deal with selecting appropriate tests and then costing those tests. It is unclear why the responses for 11B should sit so distinctly apart from the rest of that MbT Section, except that Question 11 is the only questions of the four in that section that deal with scheduling. Notwithstanding that 11A does satisfy the criteria, perhaps then it is the fact that 11B is the final question of this section, which may have led to respondents spending less time answering it. We only have anecdotal evidence to suggest that this may be true. Further investigation is warranted but could not be conducted due to timing issues.

Similarly, Question 18 leads on from Question 17. In this section respondents are asked to evaluate a set of entered data and to identify if any errors exist (Q17). Where errors did exist, respondents were then asked to identify whether they believed this were caused by human error, machinery error, or both (Q18). The question was intended to probe the respondent's deduction (industry-aligned metric: "consider implications"). Through the drafting process it was felt that this was a less well-defined question than others. It was felt that this question was more subjective in its approach. This is supported by the findings in Section 6.3.5 (see the student's comments regarding "Q20"). Her discussion around the ambiguity and misinterpretation would imply that this question is not straight-forward to answer.

7.3.5 Internal validity (sensitivity)

The difficulty and discriminability of each item is shown in Table 7-4. Difficulty is measured on a continuous scale with the midpoint of zero indicating that 50% of respondents correctly answered this item. Higher difficulty scores (*i.e.* greater than zero) indicate fewer respondents correctly answering the item. It is desirable to have a spread of values indicating a range of item difficulties. Discriminability is the comparison of respondent ability (*i.e.* CT ability) and probability of correctly responding to the item. Negative discriminability values must be avoided as they indicate that respondents of lower ability appear to be more likely to correctly respond to that item than respondents of higher ability. This indicates ambiguity or flaws in the assessment item. Furthermore, the assumption of unidimensionality (assuming that the MbT is only measuring CT) could not be robustly conducted due to the number of responses received.

All items were included in this analysis. Sub-items are also shown where appropriate. Blank answers were taken as non-responses and were excluded. Note that desirable difficulty values lay in the range -4 to 4 and discriminability values lay in the range greater than +1 (Baker & Kim, 2017).

Item difficulty ranges from extremely easy (Q16, difficulty = -25.4) to appropriately difficult (Q5, 4.1). Allowing for an acceptable range of -4 to 4, as suggested by Baker and Kim (2017), questions 10, 13 and 16 should be revised or excluded. These items are all too easy. Question 10 only requires the respondent to correctly transcribe cost information from other sheets. Question 13 only requires respondents to logically follow a diagram without the need for any deductive leaps. Question 16 provides a closed list of response from which the respondent selects. This question would suffer from the same limitations as multiple-choice questions (guessing, elimination of obviously incorrect answers) however the online platform restricts the presentation format of this question.

Item discriminability ranges from unacceptable (less than 1.0) through to strong discrimination (Q3A, 28.6). Sections 2, 3, 4 and 7 fully need to be reviewed along with questions 13 and 16.

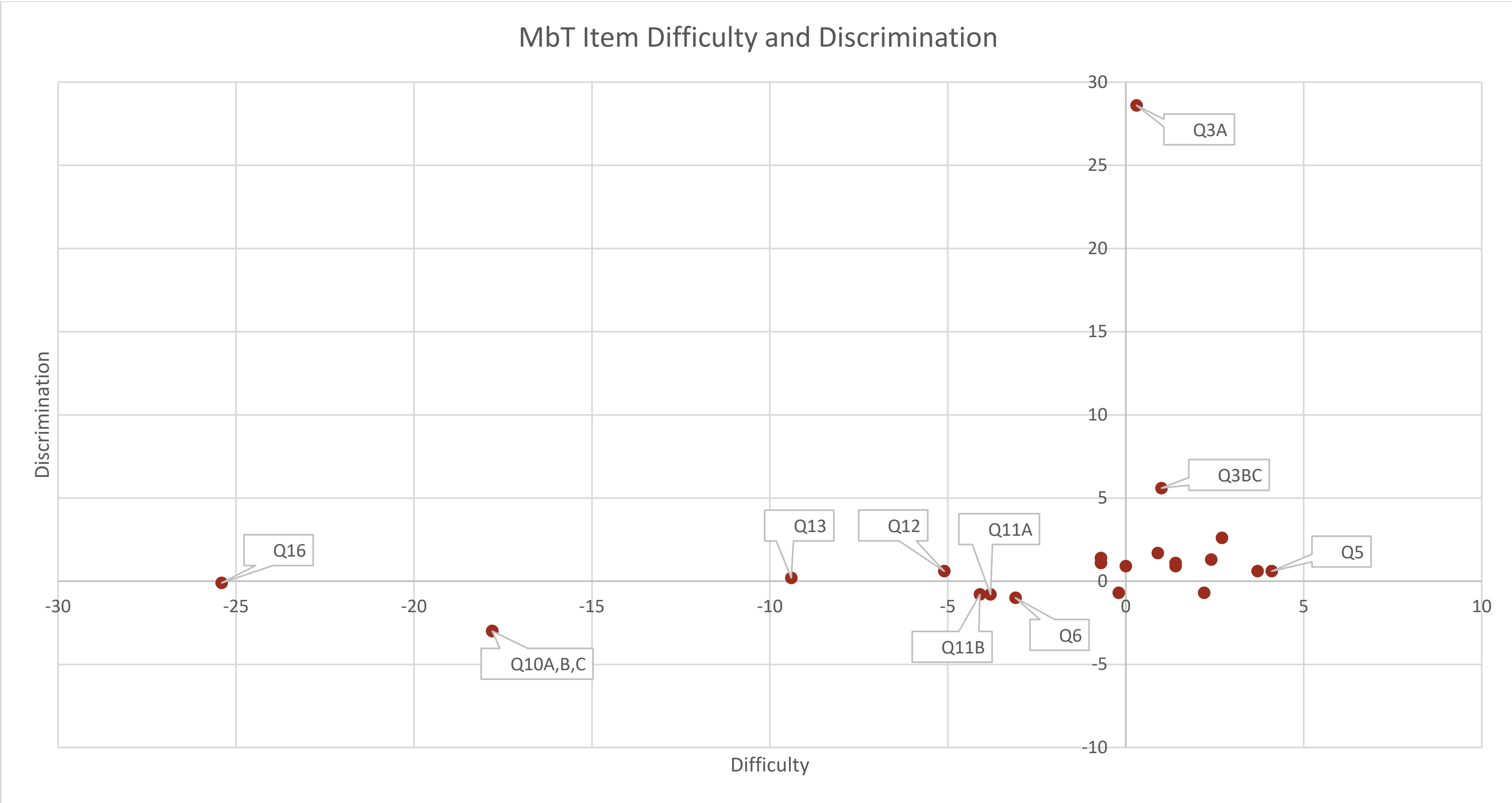

Figure 7-3. Graph of MbT item difficulty and discrimination, with some items indicated for reference.

Table 7-4. IRT 2PL analysis indicating difficulty and discriminability scores for each MbT item.

Item	**Difficulty**	**Discrim.**
Section 1		
Q1	-0.7	1.1
Q2	2.4	1.3
Q3A	0.3	28.6
Q3BC	1.0	5.6
Q4A	-0.7	1.4
Q4BC	0.9	1.7
Section 2		
Q5	4.1	0.6
Q6	-3.1	-1.0
Q7	1.4	0.9
Section 3		
Q8	3.7	0.6
Q9	0.0	0.9
Q10A	-17.8	-3.0
Q10B	-17.8	-3.0
Q10C	-17.8	-3.0
Q11A	-3.8	-0.8
Q11B	-4.1	-0.8
Section 4		
Q12	-5.1	0.6
Section 5		
Q13	-9.4	0.2
Q14	1.4	1.1
Section 6		
Q15	2.7	2.6
Q16	-25.4	-0.1
Section 7		
Q17	2.2	-0.7
Q18	-0.2	-0.7

7.4 Final observations

7.4.1 Perceived contextualised critical thinking

Follow-up feedback from the subgroup respondents lends weight to the argument around the context validity of the MbT. It is noted that these respondents are all third-year students, some of whom have completed industry-based placements. In comparing the CCTST-N and the MbT, respondents felt that the MbT is “[assessing] the things that I might have to do when I graduate and do that job”. In comparison the CCTST-N was labelled as “surface level [testing]”, “generic”, and “trying to test many fields not specific to my degree”. The apparent view of this subgroup was that the MbT, in comparison to the CCTST-N, was more targeted to their circumstances which increased their willingness to engage with it but would also limit the ability of the MbT to be used in its current form in other disciplines. This aligns with our intention for the MbT to be reflective of the industry into which these students may enter after graduating.

While this feedback was collected unsolicited and outside the scope of the original study, it demonstrates a clear difference in perception between the CCTST-N and the MbT. This is a crucial aspect of CT assessment in that the MbT may elicit stronger test-taking motivation from participants than generalised CT assessments, like the CCTST-N. Further support of this view is the observation that more than 70 students (of 320 total students) were willing to devote up to six hours to fully complete the MbT at least once for no reward other than the feedback from the MbT. This is particularly pertinent in the view of Liu *et al*. (2016) in which differences in test-taking motivation lead to an “alarmingly large” performance gap between the highly-motivated and lesser-motivated respondents. Liu *et al*. (2016, p. 691) notes that the concern around motivational impact for low stakes testing is an area of ongoing research interest. Further validation studies on low stakes assessments would benefit from analysing test taker motivation as a mediating factor in performance.

7.4.2 Duration and digitisation

We conceived the MbT to be completed within a single one-hour session on-campus through an online system. As a redundancy measure, the respondents were given a three-hour session to work through each MbT section sequentially. The MbT and its auxiliary documents were provided digitally with paper backup in case of technology failure. However, the reality of these sessions showed us that our students preferred to use the paper-based version to evaluate the items and then respond on the digital version. We suspect this may come from exam experiences at university where students are accustomed to paper-based working. Studies looking at the implementation of electronically-administered exams (e-exams) compared to traditional paper-based exams have noted several drawbacks of the e-exam format that may show parallels with the electronic presentation of the MbT. Students have self-reported perceptions of unfamiliarity with the electronic format (Wibowo, Grandhi, Chugh & Sawir, 2016) perhaps indicating a greater degree of comfort with the written word or an acclimatisation to a paper-based format. However, sessions of familiarisation with an online system may be useful in alleviating student concerns (Hillier, 2015). Our students also took up to two three-hour sessions to complete all sections of the MbT, far in excess of what we had considered necessary. Anecdotal observations would indicate that these students were not utilising technology to its fullest capabilities. For example, one item asks students to select between one and nine experiments to conduct to collect missing data, with the ideal solution requiring the least number of total experiments. One key MbT skill being assessed here is that of *systematicity*; working through the problem in a systematic and rigorous manner. Results would indicate that students did not consider all the potential combinations (which is achievable through any spreadsheet editor) and instead started by selecting the most obvious experiment and then randomly selecting other experiments until they stumbled on a solution. They were then observed going back and randomly trying alternate solutions, presumably to happen across an improved answer. This item was deliberately set up to avoid the most obvious experiment. This pseudo-random approach to problem solving took much longer than we anticipated and perhaps gave the respondent little confidence in their response.

7.4.3 Item formats

The digitisation of the MbT was core to being able to administer to a large cohort and provide feedback quickly. An additional benefit was that the MbT could be administered on any internet-enabled device allowing for the collection of observational data such as time taken to complete each item and the number of times each item is revisited, both of which would indicate difficulties or ambiguities with that item. Future digital assessments could consider these metrics as further validity evidence.

7.5 Conclusions

The main purpose of this study was to provide preliminary evidence for validity of the Monash businessThink (MbT) assessment of industry-aligned CT skills. The MbT was found to diverge from another measure of CT, the CCTST-N, which supports the idea that the MbT is assessing a different CT framework to the CCTST-N. The industry-based nature of the MbT was found to statistically significantly different to the generalised CT skills of the CCTST-N. Additionally, MbT scores were found to correlate positively with GPA with a 0.37 standard deviation performance improvement for those with GPA greater than 3.50 which aligns with other research findings (Liu *et al*., 2016). Favourably, no correlations were found between MbT scores and domestic/international status, nor first-in-family status indicating that the MbT is sufficiently accessible to all students. While no correlation was found with year-level, presence of industry experience indicated a better result on the MbT. While the MbT was shown to be consistent in its scoring, multiple assessment items were flagged for review due to low reliability or poor discriminating behaviour. Anecdotal feedback supported the industry context of the MbT in preference to generalised CT assessments. This may have led to increased respondent test-taking motivation.

In summary, this study indicated that the MbT does not yet have sufficient validity evidence and warrants a review of a number of items. However, this study does support the industry-based context of the MbT with preliminary evidence suggesting an improvement in student motivation over other generalised CT assessments. While the items themselves do not have sufficient validation, the structure and the design of MbT is unique in providing a means of assessment that engages our students in industry-based CT. Considering the duration of the MbT and the apparent appeal of its context to students, further work in this area will look at developing the MbT into a series of workshops to teach industry-aligned CT skills.

Postface

Although not included in this data, student feedback regarding the use of brownies as incentive resulted in a 100% satisfaction rating. Unfortunately, the MbT did not fare as well as these statistical tests indicate the need for a substantial re-evaluation of the test items. While the dissertation ends at this point, the next chapter does provide some options that build on the learnings of the process to develop and validate the MbT.

Chapter 8

Synthesis

8.1 Review

Having arrived at the end of 169 pages of studies we may be thinking '*well that's nice, so what now?*' or more likely '*I wish there was a summary version so I didn't have to spend so many hours reading*'. Below, we will find the response to both these points.

In *Chapter 1* we were introduced to the core ideas and problems behind teaching and assessing critical thinking (CT). Although poorly defined, CT is increasingly becoming a core competency for university graduates to master. This is especially true in the science, technology, engineering, mathematics, and medicine (STEMM) disciplines. In these, CT is either embedded as an explicit educational outcome (in pharmacy and nursing for example where the accrediting bodies call for CT competency) or is explicitly endorsed and requested by companies hiring graduates from STEMM degrees. One core difficulty in teaching and assessing CT is whether to treat CT as a set of general skills that are transferred between different domains/work areas/industries, or as a set of skills specific to the domain in which they are used. Prior research has indicated that students have had difficulty in transferring CT skills into new areas, but potential solutions exist, such as explicitly teaching CT skills using authentic/real-world tasks.

Looking now at assessment, it is evident that there is no real-world test of CT skills that aligns with the types of work that graduates from the Bachelor of Pharmaceutical Sciences. While other assessments of CT do exist, these have been previously used predominately in nursing and pharmacy with a focus on clinical decision-making. Other widely available CT assessments, such as the California Critical Thinking Skills Test, take a generic, non-contextualised approach to assessing CT thus potentially falling foul of the issue of CT skills transferability. That then presents an opportunity to develop a CT assessment that aligns with the real-world experiences of graduates from the Bachelor of Pharmaceutical Sciences.

Chapter 2 invites us to consider the real-world experiences of these graduates. This study considered the motivations of first-year Bachelor of Science, Pharmaceutical Sciences, and Pharmacy students. Third-year Pharmaceutical Sciences students provided a point of comparison on post-graduation intentions from this degree. From this study we can see that there is a strong motivation to attend university as a means to securing employment, and the choice of specific course mostly coming down to interest in the area of study. Most importantly, the results from the first- and third-year Bachelor of Pharmaceutical Sciences students showed that graduates progressively shift towards wanting to enter the workforce once they graduate. Ultimately, more than two-thirds of graduates will directly enter the workforce. So, if we want to know what are the real-world experiences of these graduates, we need to look at the work they are doing in industry.

There is a potentially wide range of industries that our graduates can enter; and preliminary evidence on alumni employment supports this view. Taking the view that CT skills are context-bound, in *Chapter 3* we look only at those industries whose work aligns with the teaching intentions of the Pharmaceutical Sciences course. That is to say that we are not interested in the views of the banking sector even if they have employed a small number of graduates from our course; banking is not the mainstay of the course. In this study industry partners are surveyed about their understandings of CT and how CT is demonstrated in their workplace. In this way we can see how industry conceptualises CT in their context.

The main finding from this study is a set of CT metrics that attempts to capture how industry conceptualises CT; *systematicity* (working through a problem in a logical manner), *business-sense* (arriving at solutions that are appropriate for the business), *multiple solutions* (comparing and contrasting more than one solution), *consideration of implications* (determining impacts from one's decisions), and *identification/awareness* (identifying issues either pre-emptively or through determining the root cause). Additional findings reinforced the idea that it is the role of the university to be developing CT skills in students. These skills can then be refined in the workplace. In the view of these respondents, the lack of these skills may result in poor graduate employability.

With much discussion around how industry wants graduates to have these skills, *Chapter 4* takes a brief look at whether CT skills are explicitly requested of graduates. Looking over twelve-months of job advertisements that are relevant for our graduates, it became clear that industry was better at using other higher-order thinking words, rather than CT-related words. These findings were consistent across industries, expected salary, company size or job permanency. This study reinforces the need to develop a common language around CT that both industry and academia can share to the benefit of graduates.

Armed with a novel understanding of CT in the context of the pharmaceutical sciences, *Chapter 5* explores whether we can find any currently-available CT assessment that aligns with our understanding of CT. We look at a pair of widely-studied CT assessments in STEMM, the California Critical Thinking Skills Test (CCTST) and the California Critical Thinking Disposition Index (CCTDI). These tests should be able to detect improvements in CT skills across year levels and any changes in student disposition to using CT skills. Using students from four year levels we can assess the validity and utility of these tests. This study was limited by the sample size (mostly an issue of cost) and so the findings are taken cautiously. Nonetheless, while the CCTST and the CCTDI were able to detect expected changes to CT skills and dispositions over twelve-weeks, they were not able to detect changes between year levels. Feedback from participants also indicated a potential lack of test-taking motivation due to the CCTST not being tailored to their particular context. Test-taking motivation has previously been found to have a significant effect on test scores. These findings support our initial suspicions around the issues of CT assessments that do not reflect the workplace context of our students.

Chapter 6 introduces the Monash businessThink (MbT) as a way to appropriately assess CT in our context. The MbT is intended to be a semi-realistic representation of work in industry. From the outset we intend that the MbT can be completed in a single one-hour session so that it can be easily incorporated into current classes. With large cohorts in our courses, we desired to have the tool be automatically marked. This required us to administer the MbT digitally and limited the types of responses that we could collect. This chapter outlines the drafting and validating process. This chapter looks at different CT assessments to determine that closed-response (*e.g.* fill-in-the-blank, multiple-choice questions) tests are most practical. To best represent industry, the MbT respondents would use a set of auxiliary documents to answer requests from a manager of a consumer goods company. The auxiliary documents reflect real-world document types while the requests are built from case studies in industry. The questions (or task items) themselves are designed to have hundreds of combinations with one optimal response. In this way the respondents have only a closed set of options to choose from, but too many responses to be able to guess the answer. The chapter provides more detail on this process.

The chapter also discusses the first validation exercises and the changes made as a result. The MbT underwent *face validation* to assess how well it reflected the reality of working in industry. A *language review* and *student review* provided further insight into how the MbT was structured and presented.

The final validation exercises are presented in *Chapter 7*. A pilot study was used to determine the MbT *test-retest validity*, *convergent and divergent validity*, *readability, internal reliability*, and *sensitivity*.

Ideally *test-retest validity* should indicate that respondents have receive similar scores when tested twice within a short number of weeks. Most sections of the MbT passed this test suggesting that respondents are not guessing the answers, and using similar thinking processes each time.

Convergent and divergent validity assess whether the MbT is actually measuring CT by comparing its results with another validated CT assessment (convergent validation), and by comparing results with expected unrelated variables such as age and gender (divergent validity). As we previously noted that no other CT assessments are similar to the MbT, it is unsurprising that the MbT did not pass the test of convergent validity when tested against the CCTST. In testing divergent validity, the MbT was successful in not correlating with domestic/international status, first-in-family status. These indicate that the MbT does not exhibit large language or cultural influences. Additionally, the results of the Flesch-Kincaid test of Readability suggest that the MbT is linguistically pitched at an appropriate level. However, the MbT did correlate with grade-point average (a measure of academic achievement). Two possible explanations of this correlation are that either the MbT is acting as an assessment of other skills that make a student successful at university, or, CT is a key skill in students being successful at university. Other research suggest that the latter is a strong possibility.

Internal reliability is a measure of how well the questions act as an homogenous test. Several questions were flagged for redesign at this step. Finally, *sensitivity* (also called *internal validity*) is a measure of the difficulty and discriminability of each question. Again, several questions were flagged due to inappropriate difficulty (mostly, exceptionally easy questions) or poor discriminability. The MbT did not fare well in this testing.

In summary, the current form of the MbT does attempt to address some of the issues around testing CT in the university sector. The MbT stands apart from other CT assessments in being tailored to the experiences of its intended audience with specific focus on the use of CT in the workplaces they will likely enter after graduating. While the MbT in its current form is not useful as an assessment, its questions and documents can act as a series of scenarios for teaching in a workshop setting.

8.2 Concluding remarks

Through this process several novel findings and approaches have been uncovered. Firstly, a new approach to understanding CT from the perspective of industry now provides another perspective from which to consider and define CT. While this work does not aim to redefine or displace current conceptions of CT, it does reinforce the need to engage with industry to better understand CT from a pragmatic perspective. It also highlights the need for industry and academia to develop a common language around CT so as to accurately express the requirements and expectations around jobs.

At the start of this thesis it was noted that employers of graduates of the pharmaceutical sciences expect greater analytical and evaluation skills in their employees (see Section 1.3.1). While this thesis does not directly address this desire for greater skills, it does set the groundwork for further research into this area for without assessment of CT skills, it is impossible to determine whether any relevant CT teaching intervention has been successful.

Accordingly, it would appear then that a major finding of this body of work has been in starting address the misunderstandings of CT between industry and academia. Through this research it has become apparent that a diversity of definitions and conceptualisations of CT exist, each with merit across a multitude of contexts. At least for our context, the novel understanding of industry-aligned CT metrics has been uncovered (see Chapter 3) and may set the foundation for further CT research in this discipline area.

Next, this work highlights the limitations of currently-available tests of CT. While researching this topic, it was noted that there are many instances in which tests of CT are being used either as a university or college pre-admission test, or an in-course assessment. These occur both in STEMM and non-STEMM disciplines. Using tests in these ways will have real-world implications for students, their jobs, and their futures. At the very least these tests should not be used as a stand-alone high-stakes assessment, and further research should be conducted into their use across a wide range of fields and wide range of cultural and educational contexts.

In validating the MbT, it became apparent that this assessment tool is not finalised as it did not meet the validation and reliability criteria set out (see Chapters 6 and 7). Without a full set of validation and reliability exercises successfully completed, it would be difficult to see how the MbT could be utilised as a formal CT assessment in its current form. Most hearteningly, the face validity, divergent validity, and test-retest scoring consistency indicate that the MbT has merit in: accurately portraying the work styles of industry through industry-based scenarios; having sufficient clarity and expression so as to render the MbT accessible to naïve and experienced pharmaceutical sciences students; and having an appropriately structured format and presentation that enables proper student engagement with the tool rather than rote memorisation.

Lastly, the development of the MbT provides a novel method for generating large numbers of assessment questions in ways that avoid issues of guessing or 'gaming the test'. In essence it is an extension of a *fill in the blank* question, however the ability to generate many hundred or thousand potential responses gives the question an element of open-response, while in fact being a closed-response question. Further investigation into the relative cognitive loads of this style of questions (as compared to multiple-choice questions) and its effects on test taking behaviour and achievement is not captured herein and so is warranted. Although only appropriate for testing skills and abilities (rather than knowledge), instead of relying on multiple-choice questions when assessing large cohorts, this '*systematic responses*' *approach* provides a valuable alternative for educators.

End Matter

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Appendices

10.1 Appendix 1. Chapter 3: Supplementary Table – Emergent Categories

Table 10-1. Industry interview emergent categories, descriptions, and explicatory example.

Category	**Description**	**Example**
Actions		
Breakdown the problem	To take a problem and determine the smaller aspects or problems to be solved.	"'Can I get down to the very basic question, basic building blocks that put my project together?' From this I can build up."
Ask the right questions	To ask probing, relevant questions to gain information.	"Ask for help and learn from experienced people around them to get a better output then doing it on their own."
Collaborate	Teamwork; workshopping solutions.	"How do we find the solution? From when I see a critical thinker would be; let me understand the problem really well, what is the scale of the problem, is this something I can do on my own or do I need help from others."
Consider implications	An awareness and understanding of the effects of one's decision or recommendations.	"From my perspective a strong critical thinker will think about the endpoint; how will we solve the problem but not introduce more problems as part of it."
Create	The act of doing / collecting / creating, after having arrived at a conclusion.	"You have the start of it which is 'let's plan, let's think about everything.' You have the end of it which is the conclusion. … But you don't have a middle section where you actually do the stuff."
Make observations	Collecting data; making key observations.	"I think that is probably the key because going on from the observation point of view, making those key observations and then understanding and for next steps what it means."
Traits		
Attention to detail	Being thorough in collecting data or problem-solving.	"When you go back and look at it you find that the methodology or the way they went about flushing out the root cause was not very thorough or comprehensive."

Category	**Description**	**Example**
Attitude	Personal traits that guide professionalism and problem-solving.	"There's definitely been examples where people who aren't good at critical thinking say 'I just have no idea, I can't make any more of these there's nothing else I can do' and pretty much give up."
Initiative	To extend oneself and/or follow-up one's actions.	"Demonstration of ability to go above what is asked and ask questions to understand concepts."
Innovation/Creativity	Lateral thinking; developing novel concepts or approaches.	"I think creativity should definitely be in there, because I don't think that should be ruled out from science."
Good business sense		
Business-sense	An awareness of the constraints of working within the business context, in relation to time, resources, *etc*.	"Whilst we would weigh out the risks and benefits and understand that the customer has to get this product on the market in the next period of time and at a certain cost."
Independence	The ability to work without guidance in regard to self-learning or problem-solving.	"And to me that's value of having critical thinking and embedded in an employee is that they can make decisions themselves without the need for guidance."
Problem-solving approach		
Common language	The use or awareness of precise terms when discussing problem-solving and its approaches.	"'What is critical thinking?' Well we haven't been able to define critical thinking but every time this pops up you are doing it without thinking."
Does not have to be the 'correct solution'	Undertaking the process of arriving at a solution even if that solution is not eventually selected.	"At the graduate level, if they can come provide a solution, it doesn't necessarily be the right one, that's the first step for us."
Multiple solutions	Providing multiple viable recommendations/solutions.	"Not only thinking about possible solutions but exploring several and then prioritising the one with the biggest chance."
Systematicity	A disciplined, orderly approach to the problem-solving process.	"… our pain lays in this space. Sometimes we just don't know that is something that we need to refer to because our processes here just haven't defined that."
Transferability	Adapting knowledge and a problem-solving approach to new situations.	"Someone who is able to think critically, you can grab that person and put them in a situation and they should be able to apply that same skill regardless of what topic you are talking about."

Category	Description	Example
Employability outcomes		
Affects employability	That a lack of CT may impact on a graduate getting a job, or being successful in that job.	“Maybe then I don’t select them if they don’t have a particularly strong critical thinking / problem solving approach. Maybe less likely to select them, to come through the process. We look for that skill.”
Cultural/job fit	That the graduate employee is a good match for the current team and job requirements.	“If you can’t get along with our team, we won’t hire you or you won’t last here.”
A degree is sufficient	That having a relevant degree is more important than one’s GPA.	“Whether it is 51% or a 99% you still have a degree. Everything above the pass line is forgotten in the real world because it comes down to that key criteria.”
Desire, not just academic skills	During the hiring process, non-academic skills are highly valued.	“I think it shows that if they’ve achieved good results while doing other things, not just 100% focused on the study.”
Prior experience	Relevant and indirect work experiences are valued.	“Another has worked at Crown [Casino] so they’ve dealt with drunk people and people yelling at them and difficult situations.”

10.2 Appendix 2. Chapter 4: Word Categories

For each root word presented here, we also considered the *verb-form* (first-, second-, and third-person in present tense, simple past tense, past perfect tense, and gerund form), *noun-form*, and *adverb-form*.

Bloom's Revised Taxonomy (*Evaluate*) (adapted from Anderson and Krathwohl (2001))	**Bloom's Revised Taxonomy (*Create*) (adapted from Anderson and Krathwohl (2001))**	**Bloom's Revised Taxonomy (*Create* cont.)**
critique	act	integrate
debate*	adapt	interface
decide	animate*	invent*
decision make (decision-make)	arrange	make
deduce*	assemble	manage
defence (-se)	brief	maximise (-ize)
detect	budget	minimise (-ize*)
determine	build	model
diagnose*	categorise (-ize*)	modify
discriminate*	change	negotiate
disprove*	code	network
estimate*	collect	organise (-ize)
evaluate	combine	originate
grade	compile	outline
judge*	compose	overhaul*
justify*	consolidate	perform
mark	construct	plan
measure	correspond	portray*
mediate*	create	predict
prioritise (-ize)	cultivate	prepare
proof	debug*	prescribe
rank*	delete*	produce
rate	depict*	program
recommend	design	propose
reconcile	develop	rearrange*
resolve	devise	reconstruct*
score	dictate*	relate
select	discuss	reorganise* (-ize*)
support	elaborate*	revise
uphold	enhance	rewrite*
validate	exchange	set up (set-up)
value	expand	show
verify	explain	solve
	facilitate	specify
	forecast*	substitute

	formulate	summarise (-ize)
	frame	suppose*
	generalise* (-ize*)	synthesise (-ize)
	generate	teach
	hypothesise* (-ize*)	tell
	imagine	test
	implement	theorise* (-ize*)
	improve	trouble shoot (troubleshoot, trouble-shoot)
	incorporate	unify*
	infer*	write
	initiate	

Critical thinking explicit indicators	**Critical thinking actions (adapted from Facione (1990))**	**Critical thinking metrics (Pearl *et al.*, 2018)**
analytical thinking*	analyse (-ze)	acuity*
critical reasoning	appraise*	acumen
critical thinker	assess	appreciation
critical thinking	calculate	aware
critically reason*	clarify	awareness
critically think*	classify	business aware (business-aware*)
forward thinking*	complete	business sense* (business-sense)
innovative thinking*	conceive*	competent
lateral thinking*	conclude	considering implications*
problem solve	conject*	diverse
problem-solve*	construe*	effects
reason critically*	decode*	expertise
solve problem(s)	define	expertly
think critically	describe	methodical
	establish	methodology
	examine	multifarious*
	gauge*	multiple solutions*
	identify	numerous
	illustrate*	ordered
	inspect	organisation (-ization)
	interpret	proactive thinking*
	investigate	proficient
	name*	ramification*
	pinpoint*	repercussion*
	present	several
	realise (-ize*)	structure
	recognise (-ize*)	systematic
	research	systematicity*
	scrutinise* (-ize*)	various
	state*	
	translate	

Critical thinking standards (adapted from Paul and Elder (2008))	**Critical thinking standards (cont.)**	Critical thinking standards (cont.)
accuracy	implausible	relevance*
applicable	important	right
apposite*	inapplicable*	rough*
approximate	inclusive	sensible*
bias*	incorrect*	serious
breadth/broad	indistinct*	shallow*
clear	inexact*	significant
coherent	insignificant*	sound
compelling*	intelligently* (-gible*)	specific
comprehensive (-sible*)	irrational*	subjective*
congruent*	just (fairness)	suitable
correct	limited	superficial*
credible*	logic	trivial*
crucial	lucid*	truth*
depth/deep	meaningless*	unbiased*
equitable*	minor	unconnected*
essential	narrow*	unfitting*
exact	objective	unimportant*
explicit*	obscure*	unjustifiable*
extensive	open minded*	unprejudiced*
fair*	partial*	unreasonable*
false*	precision	unrelated*
flawed*	predisposed*	vague*
illogical*	profound*	wrong
impartial*	rational*	

*All forms of these words had no instances in any of the job advertisements.

10.3 Appendix 3. Chapter 4: Computer Code 1 – Job Advertisement Cutter

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Globalization;
using System.IO;

// This program processes each job advert to remove website styling and CSS, leaving the job advert details, the advert t
ext and the advert questions
// 1- import each list of job adverts (HTML format) (a.k.a. zLists)       [DONE]
// 2- read each job advert code and determine output file paths/names     [DONE]
// 3- process each advert to remove unwanted HTML code (catch errors)     [DONE]
// 4- write out data    [DONE]

namespace Cutter
{
    class Program
    {
        public static string zListPath;           //path to zList directory
        public static string currentZList;
        public static string HTMLPath;            //path to HTML directory
        public static string HTMLFileNameIn;      //holder for the current HTML file name
        public static string HTMLFileNameOut;     //holder for the current HTML file name (name to be written)
        public static string HTMLFilePathOut;     //holder for the current HTML file path (to be written)
        public static string HTMLFileNameOutError;
        public static string HTMLFilePathOutError;
        public static int totalprocessed;

        public static int NumberOfErrorsAllowed;


        static void Main(string[] args)
        {
            Program n = new Program();
```

```
            try
            {
                NumberOfErrorsAllowed = 5;
                totalprocessed = 0;

                List<string> summaryFile = new List<string>(new string[191]);
                List<string> holdHTMLListing = new List<string>(new string[10001]);
                List<string> holdHTMLContent = new List<string>(new string[1500]);
                string[] HTMLOut = new string[500]; //max. 500 lines in HTMLExtract
                string[] HTMLExtractError = new string[NumberOfErrorsAllowed]; //holder for up to 10 error codes from HTM
LExtract

                // Populate the zList files for further processing
                PopulateContentFiles(summaryFile);

                // Find local path to the files
                zListPath = @LocalPath;

                HTMLPath = @LocalPath;

                // Extract the content of each zList file
                for (int i = 0; i < summaryFile.Count; i++)                //For each zList file as stored in summaryFile
 ...
                {
                    holdHTMLListing = File.ReadAllLines(zListPath + summaryFile[i]).ToList();    //... read each line to
get HTML referrer, ...
                    currentZList = summaryFile[i];

                    for (int j = 0; j < holdHTMLListing.Count; j++)        //... then read each line of the referred HTML
 to get the HTML code.
                    {
                        HTMLFileNameIn = holdHTMLListing[j].Substring(holdHTMLListing[j].Length - 13);  //get its current
 name
                        HTMLFileNameOut = "REDUCED\\reduced_" + HTMLFileNameIn;                         //determine its n
ew name
                        HTMLFilePathOut = holdHTMLListing[j].Replace(HTMLFileNameIn, HTMLFileNameOut);  //determine its w
rite path
```

```
                        HTMLFileNameOutError = "REDUCED\\error_" + HTMLFileNameIn;                      //determine error
-equivalent name
                        HTMLFilePathOutError = holdHTMLListing[j].Replace(HTMLFileNameIn, HTMLFileNameOutError);

                        //read in the HTML file contents
                        holdHTMLContent = File.ReadAllLines(holdHTMLListing[j]).ToList();

                        //display which advert you are processing
                        Console.WriteLine(summaryFile[i] + " : [" + (j + 1) + "/" + holdHTMLListing.Count + "] : " + HTML
FileNameIn + " : " + (totalprocessed + 1).ToString("#,#", CultureInfo.InvariantCulture));

                        //run HTML code through the extractor
                        HTMLOut = HTMLExtractInfo(holdHTMLContent);

                        // check for collected errors from "HTMLExtractInfo()"
                        if (HTMLOut[0].Contains(" 0 error"))
                        {
                            List<string> temphold = new List<string>(HTMLOut);
                            temphold.RemoveRange(0, NumberOfErrorsAllowed + 2);  //clean-up unneeded error data
                            HTMLOut = temphold.ToArray();
                            System.IO.File.WriteAllLines(HTMLFilePathOut, HTMLOut);
                        }
                        else
                        {
                            List<string> temphold = new List<string>(HTMLOut);
                            temphold.RemoveRange(NumberOfErrorsAllowed + 2, temphold.Count - (NumberOfErrorsAllowed + 2))
;  //clean-up unneeded error data
                            HTMLExtractError = temphold.ToArray();
                            System.IO.File.WriteAllLines(HTMLFilePathOutError, HTMLExtractError);
                        }
                        totalprocessed++;
                    }
                }
            }
            finally
            {
                Console.WriteLine();
                Console.WriteLine("Done. Press [enter] key ...");
```

```
                Console.ReadLine();
            }
        }

        public static void PopulateContentFiles(List<string> holder)
        {
            for (int i = 0; i < holder.Count; i++)
            {
                holder[i] = "zList_" + (i).ToString("000") + ".txt";
                //Console.WriteLine(holder.ElementAt(i));
            }
        }

        public static string[] HTMLExtractInfo(List<string> HTMLIn)
        {
            int cut1Start = new int();      //i = 0
            int cut1End = new int();        //i <= cut Location 1
            int cut2Start = new int();      //i = cut Location 2
            int cut2End = new int();        //i <= cut Location 3
            int cut3Start = new int();      //i = cut Location 4
            int cut3End = new int();        //i <= E.O.F.
            //int cut4Start = new int();    // unused
            //int cut4End = new int();      // unused
            //int cut5Start = new int();    // unused
            //int cut5End = new int();      // unused
            bool skip1 = new bool();
            bool skip2 = new bool();
            bool skip3 = new bool();
            //bool skip4 = new bool();      // unused
            //bool skip5 = new bool();      // unused

            string[] ExtractError = new string[5] { "", "", "", "", "" };
            int ExtractErrorCount = 0;

            // Find and check each of the cut line locations
            cut1Start = 0;
            cut1End = ArrayContains(HTMLIn, CutLocation1);
            skip1 = false;
```

```
            if (cut1Start < 0 || cut1End < 0 || cut1Start > cut1End)
            {
                ExtractError[0] = HTMLFileNameIn + ": CUT1 Error in indexes. Start: " + cut1Start + ". End: " + cut1End;
                ExtractErrorCount++;
                skip1 = true;
            }

            cut2Start = ArrayContains(HTMLIn, CutLocation2);
            cut2End = ArrayContains(HTMLIn, CutLocation3);
            skip2 = false;
            if (cut2Start < 0 || cut2End < 0 || cut2Start > cut2End)
            {
                ExtractError[1] = HTMLFileNameIn + ": CUT2 Error in indexes. Start: " + cut2Start + ". End: " + cut2End;
                ExtractErrorCount++;
                skip2 = true;
            }

            cut3Start = ArrayContains(HTMLIn, CutLocation4);
            cut3End = HTMLIn.Count;
            skip3 = false;
            if (cut3Start < 0 || cut3End < 0 || cut3Start > cut3End)
            {
                ExtractError[2] = HTMLFileNameIn + ": CUT3 Error in indexes. Start: " + cut3Start + ". End: " + cut3End;
                ExtractErrorCount++;
                skip3 = true;
            }
            //Console.WriteLine("Cutting b/w lines: " + (cut1Start + 1) + ":" + (cut1End + 1) + ", " + (cut2Start + 1) +
":" + (cut2End + 1) + ", " + (cut3Start + 1) + ":" + (cut3End + 1) + ".");

            // Delete those lines identified above
            if (!skip3) { BlankBetweenAndTerminals(HTMLIn, cut3Start, cut3End); } //always work backwards, pass in the in
dices
            if (!skip2) { BlankBetweenAndTerminals(HTMLIn, cut2Start, cut2End); }
            if (!skip1) { BlankBetweenAndTerminals(HTMLIn, cut1Start, cut1End); }

            // Cleaning up empty lines
            for (int i = 0; i < HTMLIn.Count; i++)
            {
```

```
                HTMLIn[i] = HTMLIn[i].Trim();

                if (HTMLIn[i] == "")
                {
                    HTMLIn.RemoveAt(i);
                    i--;
                }
            }


            // Insert error data
            HTMLIn.Insert(0, currentZList + "; " + ExtractErrorCount.ToString() + " error(s)");
            HTMLIn.Insert(1, ExtractError[0].ToString());
            HTMLIn.Insert(2, ExtractError[1].ToString());
            HTMLIn.Insert(3, ExtractError[2].ToString());
            HTMLIn.Insert(4, ExtractError[3].ToString());
            HTMLIn.Insert(5, ExtractError[4].ToString());
            HTMLIn.Insert(6, "*******************************");

            return HTMLIn.ToArray();                                    //Finally return the string array
        }

        private static int ArrayContains(List<string> s, string lookup)
        {
            int index = -1;     //start with no index found

            for (int i = 0; i < s.Count; i++)      //loop over all indices
            {
                if (s[i].Contains(lookup))          //do a check
                {
                    index = i;                      //record found index
                    //Console.WriteLine("Index found: " + i);
                    break;
                }
            }

            if (index != -1)     // if have found something, recheck for any extra entries of same 'lookup'
            {
```

```
                for (int j = index + 1; j < s.Count; j++)
                {
                    if (s[j].Contains(lookup))
                    {
                        //Console.WriteLine("Bonus index found: " + j);
                        index = -2;
                        break;
                    }
                }
            }
            return index;
        }

        private static void BlankBetweenAndTerminals(List<string> s, int start, int end)
        {
            //removes from (& incl. START); be sure to remove end point as well
            if (start < 0) { start = 0; }
            if (end > s.Count) { end = s.Count; }
            s.RemoveRange(start, end - start);
        }
    }
}
```

10.4 Appendix 4. Chapter 4: Computer Code 2 – Job Advertisement Parser

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Globalization;
using System.IO;
using System.Text.RegularExpressions;

// This program processes each partially cleaned job advert. Remove the advert-
specific HTML code. Then the details need to be labelled appropriately and the ad text extracted individually
// 1- import each list of partially cleaned job adverts (a.k.a. Reduced_zLists)       [DONE]
// 2- read each job advert code and determine output file paths/names     [DONE]
// 3- process job details and output    [DONE]
// 4- process job ad text and output    [DONE]

namespace Parser
{
    class Program
    {
        public static string zListPath;           //path to zList directory
        public static string currentZList;
        public static string HTMLPath;            //path to HTML directory
        public static string HTMLFileNameIn;  //holder for the current HTML file name
        public static string HTMLFileNameOut; //holder for the current HTML file name (name to be written)
        public static string HTMLFilePathOut; //holder for the current HTML file path (to be written)
        public static string HTMLNumber;
        public static int totalprocessed;

        public static int NumberOfErrorsAllowed;

        static void Main(string[] args)
        {
            try
            {
                NumberOfErrorsAllowed = 5;
```

```
                totalprocessed = 0;

                List<string> summaryFile = new List<string>(new string[1]);            //only 1 zList to show where ALL
 the REDUCEDHTML reside
                List<string> holdHTMLListing = new List<string>(new string[2000000]);    //ALL the REDUCEDHTML listings
                List<string> holdHTMLContent = new List<string>(new string[5000]);       //Read-
in content is no more than 200 lines
                List<string[]> HTMLOut = new List<string[]>();                           //Read-out content

                // Populate the zList files for further processing
                summaryFile[0] = "REDUCED_zList_000.txt";

                // Find local path to the files
                zListPath = @LocalPath;
                HTMLPath = @LocalPath;

                // Extract the content of each zList file to get HTML referrers
                holdHTMLListing = File.ReadAllLines(zListPath + summaryFile[0]).ToList();
                currentZList = summaryFile[0];

                // Start processing DETAILS ONLY
                for (int j = 0; j < holdHTMLListing.Count; j++)        //... then read each line of the referred HTML to
get the HTML code.          //UNBOUND //=0; j++) //
                {
                    HTMLFileNameIn = holdHTMLListing[j].Substring(holdHTMLListing[j].Length - 21);  //get its current nam
e
                    HTMLNumber = HTMLFileNameIn.Replace("reduced_", "");                            //the pure name 3xxxx
xxx.html
                    HTMLFileNameOut = "DETAILS\\parsedDETAILS_" + HTMLNumber;                       //determine its new n
ame
                    HTMLFilePathOut = holdHTMLListing[j].Replace(HTMLFileNameIn, HTMLFileNameOut);  //determine its write
 path

                    holdHTMLContent = File.ReadAllLines(holdHTMLListing[j]).ToList();                        //read in th
e HTML file contents
                    Console.WriteLine("Current DETAILS : [" + (j + 1) + "/" + holdHTMLListing.Count + "] : " + HTMLFileNa
meIn + " : " + (totalprocessed + 1).ToString("#,#", CultureInfo.InvariantCulture));
```

```
                    HTMLOut = HTMLParseInfo1(holdHTMLContent);       //run through the parser (DETAILS)
                    HTMLOut = ArrayCleaner(HTMLOut);                 //run through the cleaner (DETAILS)
                    System.IO.File.WriteAllLines(HTMLFilePathOut, PreWriteEdit1(HTMLOut, HTMLNumber));

                    totalprocessed++;
                }

                //* ---------------------------------------- NEW SECTION ----------------------------------------*//
                // Start processing TEXT ONLY
                totalprocessed = 0;

                for (int k = 0; k < holdHTMLListing.Count; k++)        //... then read each line of the referred HTML to
get the HTML code.          //UNBOUND //=0; j++) //
                {
                    HTMLFileNameIn = holdHTMLListing[k].Substring(holdHTMLListing[k].Length - 21);  //get its current nam
e
                    HTMLNumber = HTMLFileNameIn.Replace("reduced_", "");                            //the pure name *.htm
l
                    HTMLFileNameOut = "ADTEXT\\parsedADTEXT_" + HTMLNumber;                           //determine its new
 name
                    HTMLFilePathOut = holdHTMLListing[k].Replace(HTMLFileNameIn, HTMLFileNameOut);  //determine its write
 path

                    holdHTMLContent = File.ReadAllLines(holdHTMLListing[k]).ToList();                        //read in th
e HTML file contents
                    Console.WriteLine("Current ADTEXT : [" + (k + 1) + "/" + holdHTMLListing.Count + "] : " + HTMLFileNam
eIn + " : " + (totalprocessed + 1).ToString("#,#", CultureInfo.InvariantCulture));

                    HTMLOut = HTMLParseInfo2(holdHTMLContent);       //run through the parser ADTEXT
                    HTMLOut = ArrayCleaner(HTMLOut);                 //run through the cleaner ADTEXT
                    System.IO.File.WriteAllLines(HTMLFilePathOut, PreWriteEdit2(HTMLOut, HTMLNumber));

                    totalprocessed++;
                }
            }
            finally
            {
```

```
                Console.WriteLine();
                Console.WriteLine("Done. Press any key ...");
                Console.ReadLine();
            }

        }

        public static List<string[]> HTMLParseInfo1(List<string> HTMLIn)
        {
            List<string[]> datahold = new List<string[]>();
            string[] tempstringarray = new string[1];
            int tempindex = new int();

            // 'StartLocand' and 'EndLocand' are HTML code that identify particular lines within the file
            datahold.Insert(0, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));

            tempstringarray = OneLineBetween(HTMLIn, StartLocand, EndLocand, 0);
            tempstringarray[1] = tempstringarray[1].Substring(0, (tempstringarray[1].Length - 2));      //removing traili
ng " -"

            datahold.Insert(1, tempstringarray);                                                        //storing
            datahold.Insert(2, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(3, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(4, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(5, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(6, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(7, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));

            tempindex = Int32.Parse(datahold[7].GetValue(0).ToString());  //extract location of last line found
            datahold.Insert(8, OneLineAfter(HTMLIn, StartLocand", tempindex));

            return datahold;
        }

        public static string[] PreWriteEdit1(List<string[]> ArrayIn, string name)
        {
            List<string> holderList = new List<string>();
```

```
            //* Give ArrayIn to holderList *//
            holderList.Insert(0, name);
            holderList.Insert(1, "*** JOB TITLE START ***");
            holderList.Insert(2, ArrayIn[0][1]);
            holderList.Insert(3, "*** JOB TITLE END ***");
            holderList.Insert(4, "");
            holderList.Insert(5, "*** COMPANY START ***");
            holderList.Insert(6, ArrayIn[1][1]);
            holderList.Insert(7, "*** COMPANY END ***");
            holderList.Insert(8, "");
            holderList.Insert(9, "*** ADVERT. DATE START ***");
            holderList.Insert(10, ArrayIn[2][1]);
            holderList.Insert(11, "*** ADVERT. DATE END ***");
            holderList.Insert(12, "");
            holderList.Insert(13, "*** LOCATION START ***");
            holderList.Insert(14, ArrayIn[3][1]);
            holderList.Insert(15, ArrayIn[4][1]);
            holderList.Insert(16, "*** LOCATION END ***");
            holderList.Insert(17, "");
            holderList.Insert(18, "*** SALARY START ***");
            holderList.Insert(19, ArrayIn[5][1]);
            holderList.Insert(20, "*** SALARY END ***");
            holderList.Insert(21, "");
            holderList.Insert(22, "*** PERMANENCY START ***");
            holderList.Insert(23, ArrayIn[6][1]);
            holderList.Insert(24, "*** PERMANENCY END ***");
            holderList.Insert(25, "");
            holderList.Insert(26, "*** INDUSTRY START ***");
            holderList.Insert(27, ArrayIn[7][1]);
            holderList.Insert(28, ArrayIn[8][1]);
            holderList.Insert(29, "*** INDUSTRY END ***");
            holderList.Insert(30, "");

            // Remove duplicate blank lines
            for (int i = 0; i < (holderList.Count - 1); i++)    //do not want the i+1 to index off the end of the array
            {
                holderList[i + 1] = holderList[i + 1].Trim();       //will only never trim holderList[0]; it always has t
he NAME, so this is fine
```

```
                if (holderList[i] == "" && holderList[i + 1] == "")
                {
                    holderList.RemoveAt(i + 1);
                    i--;
                    if (i < 0) { i = 0; }   //just in case the index reverses too far; should be impossible
                }
            }

            string[] holderString = holderList.ToArray();
            return holderString;
        }

        public static List<string[]> HTMLParseInfo2(List<string> HTMLIn)
        {
            List<string[]> datahold = new List<string[]>();
            string[] tempstringarray = new string[1];
            int tempindex = new int();

            // 'StartLocand' and 'EndLocand' are HTML code that identify particular lines within the file
            datahold.Insert(0, OneLineBetween(HTMLIn, StartLocand, @"</h1>", 0));

            tempstringarray = OneLineBetween(HTMLIn, StartLocand, @"</span>", 0);
            tempstringarray[1] = tempstringarray[1].Substring(0, (tempstringarray[1].Length - 2));      //removing traili
ng " -"
            datahold.Insert(1, tempstringarray);                                                        //storing

            datahold.Insert(0, MultiLineBetween(HTMLIn, StartLocand, EndLocand, StartLocand, EndLocand, 0));
            datahold.Insert(1, MultiLineBetween(HTMLIn, StartLocand, EndLocand, StartLocand, EndLocand, 0));

            datahold.Insert(4, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(5, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(6, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(7, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(8, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(9, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));
            datahold.Insert(9, OneLineBetween(HTMLIn, StartLocand, EndLocand, 0));

            tempindex = Int32.Parse(datahold[9].GetValue(0).ToString());  //extract location of last line found
```

```
            datahold.Insert(10, OneLineAfter(HTMLIn, StartLocand, tempindex));
            return datahold;
        }

        public static string[] PreWriteEdit2(List<string[]> ArrayIn, string name)
        {
            List<string> holderList = new List<string>();

            // Give ArrayIn to holderList
            holderList.Insert(0, name);
            holderList.Insert(1, "*** ADVERT. TEXT START ***");

            int currentIndex = holderList.Count - 1;
            for (int i = 1; i < ArrayIn[0].Length; i++)
            {
                holderList.Insert(currentIndex + i, ArrayIn[0][i]);     //skip first index as this only records the INDEX
 START info (i = 1, instead of i = 0)
            }

            currentIndex = holderList.Count - 1;
            holderList.Insert(currentIndex, "*** ADVERT TEXT END ***");
            holderList.Insert(holderList.Count, "");
            holderList.Insert(holderList.Count, "*** QUESTIONS START ***");

            currentIndex = holderList.Count - 1;
            for (int i = 1; i < ArrayIn[1].Length; i++)
            {
                holderList.Insert(currentIndex + i, ArrayIn[1][i]);     //skip first index as this only records the INDEX
 START info (i = 1, instead of i = 0)
            }

            holderList.Insert(holderList.Count, "*** QUESTIONS END ***");

            // Remove duplicate blank lines
            for (int i = 0; i < (holderList.Count - 1); i++)    //do not want the i+1 to index off the end of the array
            {
                holderList[i + 1] = holderList[i + 1].Trim();       //will only never trim holderList[0]; it always has t
he NAME, so this is fine
```

```
                if (holderList[i] == "" && holderList[i + 1] == "")
                {
                    holderList.RemoveAt(i + 1);
                    i--;
                    if (i < 0) { i = 0; } //just in case the index reverses too far; should be impossible
                }
            }

            string[] holderString = holderList.ToArray();
            return holderString;
        }

        public static List<string[]> ArrayCleaner(List<string[]> ArrayIn)
        {
            for (int i = 0; i < ArrayIn.Count; i++)             //iterate over all the entries for each HTML (0 -> 9)
            {
                for (int j = 0; j < ArrayIn[i].Length; j++)     //iterate over all the strings within each entry of the s
ame HTML
                {
                    //* Substitute the required tags *//
                    ArrayIn[i][j] = ArrayIn[i][j].Replace(" ", " ").Replace("&quot;", "'").Replace("&amp;", "&").Rep
lace("&#43;", "+").Replace("<div class=" + @"""templatetext""" + ">", "").Replace("</li>", " | ");

                    //* Remove any remaining tags *//
                    ArrayIn[i][j] = Regex.Replace(ArrayIn[i][j], @"<[^>]+>| ", "").Trim();
                    ArrayIn[i][j] = Regex.Replace(ArrayIn[i][j], @"\s{2,}", " ");
                }
            }
            return ArrayIn;
        }

        public static string[] OneLineBetween(List<string> input, string startString, string endString, int startIndex)
        {
            string[] result = new string[2];
            int extractStart = 0;
            int extractEnd = 0;

            result[0] = "-1";       //found index
```

```
            result[1] = "";         //output value

            for (int i = startIndex; i < input.Count; i++)
            {
                if (input[i].Contains(startString) && input[i].Contains(endString))
                {
                    extractStart = input[i].IndexOf(startString) + startString.Length;
                    extractEnd = input[i].LastIndexOf(endString);

                    result[0] = i.ToString();
                    result[1] = input[i].Substring(extractStart, (extractEnd - extractStart)).Trim();
                    break;
                }
            }
            return result;
        }

        public static string[] OneLineAfter(List<string> input, string startString, int startIndex)
        {
            string[] result = new string[2];
            int extractStart = 0;
            int extractEnd = 0;

            result[0] = "-1";       //found index
            result[1] = "";         //output value

            for (int i = startIndex; i < input.Count; i++)
            {
                if (input[i].Contains(startString))
                {
                    extractStart = input[i].IndexOf(startString) + startString.Length;
                    extractEnd = input[i].Length;

                    result[0] = i.ToString();
                    result[1] = input[i].Substring(extractStart, (extractEnd - extractStart)).Trim();
                    break;
                }
            }
```

```
            return result;
        }

        public static string[] MultiLineBetween(List<string> input, string startString, string endString, string startTag
, string endTag, int startIndex)
        {
            string[] HTMLExtract = new string[5000];            //the extracted info
            List<string> converterList = new List<string>();    //the list which removes empty lines

            int extractStartLine = 0;
            int extractEndLine = 0;
            int tagCounter = -1;                    // Qty of start and end tags passed
            string readingstring = "";
            string IndexStartCode = "-1";

            // Find start line
            for (int i = startIndex; i < input.Count; i++)
            {
                if (input[i].Contains(startString))
                {
                    extractStartLine = i;       //find that first line
                    IndexStartCode = i.ToString();
                    tagCounter = 0;             //enable the start of next loop
                    break;
                }
            }

            // Count occurrences of OPEN|CLOSE tags
            if (tagCounter == 0)
            {
                for (int i = extractStartLine; i < input.Count; i++)
                {
                    readingstring = input[i].ToString();        //assign the current reading string entry
                    tagCounter += (readingstring.Length - readingstring.Replace(startTag, "").Length) / startTag.Length;
                    tagCounter -= (readingstring.Length - readingstring.Replace(endTag, "").Length) / endTag.Length;

                    if (tagCounter <= 0)
                    {
```

```
                        extractEndLine = i;
                        break;      //if we have met or exceeded the number of CLOSE tags, then end the loop
                    }
                }
                for (int j = extractStartLine; j <= extractEndLine; j++)
                {
                    HTMLExtract[(j - extractStartLine + 1)] = input[j].Trim();      //insert data into Index 1++
                }
            }
            HTMLExtract[0] = IndexStartCode;     //put in any error
            converterList = HTMLExtract.ToList();   //move into list

            // Cleaning up empty lines
            for (int k = 0; k < converterList.Count; k++)
            {
                if (converterList[k] == "" || converterList[k] == null)
                {
                    converterList.RemoveAt(k);
                    k--;
                }
            }

            string[] result = new string[(converterList.Count + 1)];              //let's overestimate, safely
            result = converterList.ToArray();
            return result;
        }
    }
}
```

10.5 Appendix 5. Chapter 4: Computer Code 3 – Word Extraction

```
using System;
using System.Collections.Generic;
using System.IO;
using System.Linq;
using System.Text.RegularExpressions;

// This program takes the advert text and pulls each individual word, giving an output of a list of each used word and th
e count
// 1- pull-in 10,000 lines at a time (aware of short final block)       [DONE]
// 2- locate start and end of each job text & questions     [DONE]
// 3- for job text, count each word using delimiters (ignore numbers and punctuation)    [DONE]
// 4- build a 'dictionary' of each word (summary version and broken down by advert)  [DONE]
// 5- export the above in raw text and CSV      [DONE]
// 5- extract each job question and output      [DONE]

namespace WordExtraction
{
    class Program
    {
        // output fullDictionaryByWord to another doc
        public static DateTime startTime;
        public static DateTime processAdvertsEnd;
        public static DateTime dictionaryBuildEnd;
        public static DateTime endTime;

        // Path lists
        public static string inputFileFullPath = @LocalPath;
        public static string outputByWordSummaryFullPath = @LocalPath;
        public static string outputByWordAdvertListingFullPath = @LocalPath;
        public static string outputByWordAdvertListingFullPath_ExcelFriendly = @LocalPath;
        public static string outputQuestionsFullPath = @LocalPath;

        // Pulling text in
```

```
        public static int lineCount = 10000;          //*** number of lines in each read block
        public static List<string> fullTextIn = new List<string>(); //OLD METHOD
        public static string[] blockTextIn = new string[lineCount]; //to take 10k lines
        public static int blockCount = 0;
        public static int totalblockCount;
        public static int fileCurrentReadIndex = 0;
        public static int filePreviousReadLine = 0;

        // Current ad. processing
        public static int numExpectedAdvert = 100;  //*** or 2M
        public static int totalAdsProcessed;
        public static int totalLinesIn;
        public static int currentBlockReadIndex;
        public static int adsFound;

        public static int currentDictionaryEntry;
        public static int errorCode;
        public static int numberOfDudAdverts;


        public static List<WordDetails> fullDictionaryByWord = new List<WordDetails>();
        public class WordDetails
        {
            public string wordText;
            public int wordQuantity;
            public List<int> advertSources;
        }


        public static AdvertDetails[] fullDictionaryByAdvert = new AdvertDetails[numExpectedAdvert];
        public class AdvertDetails
        {
            public int identifier;

            public int adBlockStartLine;

            public int adTextStartLine;
            public int adTextEndLine;
```

```
            public int adQuestionStartLine;
            public int adQuestionEndLine;

            public List<WordEntry> word = new List<WordEntry>();
            public List<string> question = new List<string>();

            public void AddWord(string inputWord)
            {
                int wordPosition = new int();

                //assume that it is parsed nicely
                //Console.WriteLine("Exists {0} in list? {1}", inputWord, word.Exists(x => x.Word == inputWord));
                if (word.Exists(x => x.Word == inputWord))  // if the word already exists in this context
                {
                    wordPosition = word.FindIndex(x => x.Word == inputWord);                //check if already present, i
f so: increment
                    word[wordPosition].Qty++;
                }
                else
                {
                    word.Add(new WordEntry { Word = inputWord, Qty = 1 });                //if not, add new entry
                }
            }
        }
        public class WordEntry
        {
            public string Word;
            public int Qty;
        }


        static void Main(string[] args)
        {
            startTime = DateTime.Now;
            Console.WriteLine(startTime);
            try
            {
```

```
            totalAdsProcessed = 0;
            totalLinesIn = 0;
            currentDictionaryEntry = 0;
            adsFound = 0;
            blockCount = 1;

            // Initialise dictionary & BlockTextIn
            Console.WriteLine("Initialisation start");
            for (int i = 0; i < numExpectedAdvert; i++)
            {
                fullDictionaryByAdvert[i] = new AdvertDetails();
            }
            Console.WriteLine("Initialisation end");
            Console.WriteLine();

            Console.WriteLine("Counting lines...");
            FindLength();   // how many lines?
                            // So there are {'totalLinesIn' / 10000} blocks of 10000 lines
            totalblockCount = (totalLinesIn / lineCount) + 1;
            Console.WriteLine("{0} total lines in {1} blocks.", totalLinesIn, totalblockCount);
            Console.WriteLine();

            while (fileCurrentReadIndex < totalLinesIn)
            {
                // Pull in next block & restart read line
                ImportText(fileCurrentReadIndex, lineCount);
                currentBlockReadIndex = 0;

                // Record start time
                DateTime blockStart = new DateTime();
                DateTime blockEnd = new DateTime();
                blockStart = DateTime.Now;
                blockEnd = DateTime.Now;

                // Find location of last advert end
                int locateEndIndex = 0;
                locateEndIndex = Array.LastIndexOf(blockTextIn, "*** QUESTIONS END ***");
```

```
                    if (blockTextIn.Length < lineCount)     // catch final block because blockTextIn is shorter than expe
cted
                    {
                        Console.WriteLine("** Call short [last] block ***");
                        locateEndIndex = blockTextIn.Length - 1;
                    }

                    //Console.WriteLine("Lines {0} : {1}", fileCurrentReadIndex + 1, fileCurrentReadIndex + locateEndInde
x + 1);
                    fileCurrentReadIndex += locateEndIndex + 1; // move the fileReader foward by one more than the found
endpoint

                    // Read between blockStart to locateEndIndex; FindJobBounds / FindQuestionBounds / ImportLine / Impor
tQuestion
                    while (currentBlockReadIndex <= locateEndIndex)
                    {
                        // Find JOB bounds (finds next advert bounds)
                        //Console.WriteLine("Starting at line: " + (filePreviousReadLine + currentBlockReadIndex + 1));
                        errorCode = FindJobBounds(currentBlockReadIndex);

                        // Find Question bounds (finds next questions bounds)
                        if (errorCode == 0)     //if no problems finding AD TEXT bounds
                        {
                            errorCode = FindQuestionBounds(fullDictionaryByAdvert[currentDictionaryEntry].adTextEndLine);
                        }
                        else
                        {
                            errorCode = FindQuestionBounds(currentBlockReadIndex);
                        }


                        // Having found the bounds of the job advert & qns, extract and do something with them
                        ProcessLine();
                        ImportQuestion();


                        // Now move to the next job advert
                        if (errorCode == 0)
```

```
                        {
                            currentBlockReadIndex = Math.Max(fullDictionaryByAdvert[currentDictionaryEntry].adTextEndLine
, fullDictionaryByAdvert[currentDictionaryEntry].adQuestionEndLine);
                            currentBlockReadIndex++;
                        }
                        else
                        {
                            break;
                        }
                        currentDictionaryEntry++;
                    }

                    blockEnd = DateTime.Now;
                    Console.WriteLine("Finished line: {0} / {1} [{2}%], took {3} seconds. Fin. @ {4}", fileCurrentReadInd
ex, totalLinesIn, (float)fileCurrentReadIndex / (float)totalLinesIn * 100, (blockEnd - blockStart).Seconds, DateTime.Now)
;
                    //Console.WriteLine("Current read: {0}, totalIn {1}", fileCurrentReadIndex, totalLinesIn);
                    blockStart = DateTime.Now;
                    blockCount++;

                    filePreviousReadLine = fileCurrentReadIndex;
                }

                processAdvertsEnd = DateTime.Now;


                BuildDictionaryByWord();
                dictionaryBuildEnd = DateTime.Now;

                Console.WriteLine();
                Console.WriteLine("Writing [1/4] Word counts ...");
                WriteOut();

                Console.WriteLine();
                Console.WriteLine("Writing [2/4] Advert questions ...");
                WriteQuestionsOut();

                Console.WriteLine();
```

```
                Console.WriteLine("Writing [3/4] Word advert list ...");
                WriteWordAdvertOut();

                Console.WriteLine();
                Console.WriteLine("Writing [4/4] Word advert list (Excel-friendly) ...");
                WriteWordAdvertOut_Excel();

                // DEBUG STUFF
                //for (int i = 0; i < fullDictionaryByAdvert.Length; i++)
                //{
                //    //Console.WriteLine();
                //    //Console.WriteLine(fullDictionaryByAdvert[i].identifier);
                //    //Console.WriteLine(fullDictionaryByAdvert[i].adTextStartLine + 1);
                //    //Console.WriteLine(fullDictionaryByAdvert[i].adTextEndLine + 1);
                //    //Console.WriteLine(fullDictionaryByAdvert[i].adQuestionStartLine + 1);
                //    //Console.WriteLine(fullDictionaryByAdvert[i].adQuestionEndLine + 1);
                //}   //check fullDictionaryByAdvert all line positions
                //for (int i = 0; i < fullDictionaryByWord.Count; i++)
                //{
                //    //Console.WriteLine("Word: {0} ; Count: {1}", fullDictionaryByWord[i].wordText, fullDictionaryByWor
d[i].wordQuantity);
                //}   // display contents of fullDictionaryByWord
                //for (int i = 0; i < fullDictionaryByAdvert.Length; i++)
                //{
                //    //Console.WriteLine("{0}: {1} , {2}", fullDictionaryByAdvert[i].identifier, fullDictionaryByAdvert[
i].adTextStartLine, fullDictionaryByAdvert[i].adTextEndLine);
                //}   //check fullDictionaryByAdvert adtext line positions
                //for (int i = 0; i < fullDictionaryByAdvert.Length; i++)
                //{
                //    for (int j = 0; j < fullDictionaryByAdvert[i].word.Count; j++)
                //    {
                //        //Console.WriteLine("{0} > {1}, {2}", fullDictionaryByAdvert[i].identifier, fullDictionaryByAdv
ert[i].word[j].Word, fullDictionaryByAdvert[i].word[j].Qty);
                //    }

                //}   //check fullDictionaryByAdvert word contents
                //for (int i = 0; i < fullDictionaryByWord.Count; i++)
                //{
```

```
                //    for (int j = 0; j < fullDictionaryByWord[i].advertSources.Count; j++)
                //    {
                //        //Console.WriteLine("{0} > {1}, {2}", fullDictionaryByWord[i].advertSources[j], fullDictionaryB
yWord[i].wordText, fullDictionaryByWord[i].wordQuantity);
                //    }

                //}   //check fullDictionaryByWORD contents

            }
            finally
            {
                endTime = DateTime.Now;
                Console.WriteLine();
                Console.WriteLine("Start @: {0} | Ads processed @: {1}\nDictionary built @: {2} | End @: {3}", startTime,
 processAdvertsEnd, dictionaryBuildEnd, endTime);
                Console.WriteLine("Number of dud adverts {0}", numberOfDudAdverts);
                Console.WriteLine();
                Console.WriteLine("Done. Press enter key ...");
                Console.ReadLine();
            }

        }

        static void ImportText(int startLineZeroIndex, int lineCount) { blockTextIn = File.ReadLines(inputFileFullPath).S
kip(startLineZeroIndex).Take(lineCount).ToArray(); }
        static void FindLength() { totalLinesIn = File.ReadLines(inputFileFullPath).Count(); }
        static void InsertBlankEntry()
        {
            WordEntry blankWord = new WordEntry { Word = "", Qty = 0 };
            List<WordEntry> blankWordList = new List<WordEntry> { blankWord };
            List<string> blankQuestion = new List<string>();
            //FOR LIST//fullDictionaryByAdvert.Add(new AdvertDetails { identifier = 0, adTextStartLine = 0, adTextEndLine
 = 0, adQuestionStartLine = 0, adQuestionEndLine = 0, word = blankWordList, question = blankQuestion });
        }

        static int FindJobBounds(int startLine)
        {
            int readPosition = startLine;
```

```
            string holder;

            bool found1 = false;    // Found start point
            bool found2 = false;    // Found end point

            while (!(found1 && found2) && readPosition < blockTextIn.Length)
            {
                if (blockTextIn[readPosition] == "*** ADVERT. TEXT START ***")
                {
                    fullDictionaryByAdvert[currentDictionaryEntry].adBlockStartLine = filePreviousReadLine;            //
 Ad is in this block
                    fullDictionaryByAdvert[currentDictionaryEntry].adTextStartLine = readPosition;  // Ad starts at this
line of the block
                    holder = blockTextIn[readPosition - 1].Substring(0, 8);                         // The name is locate
d one line above; extract only the 8-digit identifier

                    if (!(holder == "*** ADVE"))                                                    // If NOT error ...
                    {
                        fullDictionaryByAdvert[currentDictionaryEntry].identifier = Convert.ToInt32(holder);
                    }
                    else
                    {
                        fullDictionaryByAdvert[currentDictionaryEntry].identifier = -1;
                        numberOfDudAdverts++;
                    }
                    found1 = true;
                }

                if (blockTextIn[readPosition] == "*** ADVERT TEXT END ***")
                {
                    fullDictionaryByAdvert[currentDictionaryEntry].adTextEndLine = readPosition;
                    found2 = true;
                }

                readPosition++;
            }
```

```
            if (!found1 || !found2)     //error check
            {
                //Console.WriteLine("Failed bools");
                return 1;
            }
            else
            {
                //Console.WriteLine("Success bools");
                return 0;
            }
        }
        static int FindQuestionBounds(int startLine)
        {
            int readPosition = startLine;

            bool found1 = false;   // Found start point
            bool found2 = false;   // Found end point

            while (!(found1 && found2) && readPosition < blockTextIn.Length)
            {

                if (blockTextIn[readPosition] == "*** QUESTIONS START ***")
                {
                    fullDictionaryByAdvert[currentDictionaryEntry].adQuestionStartLine = readPosition;// + fileCurrentRea
dIndex;
                    found1 = true;
                }
                if (blockTextIn[readPosition] == "*** QUESTIONS END ***")
                {
                    fullDictionaryByAdvert[currentDictionaryEntry].adQuestionEndLine = readPosition;// + fileCurrentReadI
ndex;
                    found2 = true;
                }

                readPosition++;
            }

            if (!found1 || !found2)     //error check
```

```
            { return 1; }
            else
            { return 0; }
        }

        static void ProcessLine()
        {
            Char[] delimiter = new Char[] { ' ', '/', '\\',
                                            '-', '–', '—', '=',
                                            ':', ';', '\n', '\r',
                                            '.', ',', '\'', '"',
                                            '(', '{', '[', ')', '}', ']',
                                            '!', '?'};

            if (fullDictionaryByAdvert[currentDictionaryEntry].adTextEndLine - fullDictionaryByAdvert[currentDictionaryEn
try].adTextStartLine >= 1)     // erroneous entries will have END-START <= 0
            {
                for (int i = fullDictionaryByAdvert[currentDictionaryEntry].adTextStartLine + 1; i < fullDictionaryByAdve
rt[currentDictionaryEntry].adTextEndLine; i++) //for (int i = fullDictionaryByAdvert[currentDictionaryEntry].adTextStartL
ine + 1; i < fullDictionaryByAdvert[currentDictionaryEntry].adTextStartLine + 2; i++)
                {
                    string[] words = File.ReadLines(inputFileFullPath).ElementAt(i).Split(delimiter, StringSplitOptions.R
emoveEmptyEntries);

                    for (int j = 0; j < words.Length; j++)
                    {

                        if (Regex.IsMatch(words[j], @"^[\p{P}\p{S}\d]"))      // if whole string matches punctuation ...
                        {
                            words[j] = "***REMOVED:punc or purely numerical***";
                        }
                        else
                        {
                            words[j] = words[j].ToLower();
                        }
                    }

                    foreach (string word in words)
```

```
                    {
                        //Console.WriteLine(word);

                        fullDictionaryByAdvert[currentDictionaryEntry].AddWord(word);
                    }
                    //Console.WriteLine(File.ReadLines(inputFileFullPath).ElementAt(i));
                }
            }
        }
        static void ImportQuestion()
        {
            if (fullDictionaryByAdvert[currentDictionaryEntry].adQuestionEndLine - fullDictionaryByAdvert[currentDictiona
ryEntry].adQuestionStartLine > 1)
            {
                for (int i = fullDictionaryByAdvert[currentDictionaryEntry].adQuestionStartLine + 1; i <= fullDictionaryB
yAdvert[currentDictionaryEntry].adQuestionEndLine - 1; i++)
                {
                    fullDictionaryByAdvert[currentDictionaryEntry].question.Add(File.ReadLines(inputFileFullPath).Element
At(i + fullDictionaryByAdvert[currentDictionaryEntry].adBlockStartLine));
                }
            }
        }

        static void BuildDictionaryByWord()
        {
            for (int i = 0; i < fullDictionaryByAdvert.Length; i++)              //for each advert
            {
                //int wordCountHolder = 0;
                //for (int k = 0; k < fullDictionaryByAdvert[i].word.Count; k++)
                //{
                //    wordCountHolder += fullDictionaryByAdvert[i].word[k].Qty;
                //}
                //Console.WriteLine("Advert {0} contains {1} words @ {2} instances", fullDictionaryByAdvert[i].identifier
, fullDictionaryByAdvert[i].word.Count, wordCountHolder);

                for (int j = 0; j < fullDictionaryByAdvert[i].word.Count; j++)  //for each word in that advert
                {
```

```
                    int wordPosition = new int();
                    int currentAdvert = fullDictionaryByAdvert[i].identifier;
                    string currentWord = fullDictionaryByAdvert[i].word[j].Word;
                    int currentQty = fullDictionaryByAdvert[i].word[j].Qty;

                    //assume that it is parsed nicely
                    if (fullDictionaryByWord.Exists(x => x.wordText == currentWord))
                    {
                        wordPosition = fullDictionaryByWord.FindIndex(x => x.wordText == currentWord);
                        fullDictionaryByWord[wordPosition].wordQuantity += currentQty;

                        if (!fullDictionaryByWord[wordPosition].advertSources.Exists(x => x == currentAdvert))  // if the
 current advert does NOT exist in the adverts list ...
                        {
                            fullDictionaryByWord[wordPosition].advertSources.Add(currentAdvert);
                        }
                    }
                    else
                    {
                        fullDictionaryByWord.Add(new WordDetails { wordText = currentWord, wordQuantity = currentQty, adv
ertSources = new List<int> { currentAdvert } });
                    }
                }
                //Console.WriteLine("{0} words found", fullDictionaryByWord.Count);
            }
            //Console.WriteLine("{0} total adverts", fullDictionaryByAdvert.Length);
        } // convert DictByAdvert to DictByWord


        static void WriteOut()
        {
            string stringOut;

            //Build header
            stringOut = "WORD,COUNT,SOURCES COUNT\n";
            System.IO.File.AppendAllText(outputByWordSummaryFullPath, stringOut);
```

```
            for (int i = 0; i < fullDictionaryByWord.Count; i++)
            {
                stringOut = fullDictionaryByWord[i].wordText + "," + fullDictionaryByWord[i].wordQuantity + "," + fullDic
tionaryByWord[i].advertSources.Count + "\n";
                System.IO.File.AppendAllText(outputByWordSummaryFullPath, stringOut);
            }
        }

        static void WriteQuestionsOut()
        {
            string stringOut = "";
            string questionHolder = "";

            //Build header
            stringOut = "ADVERT_ID,ADVERT_BLOCK,QN_STARTLINE,QN_ENDLINE,QUESTION\n";
            System.IO.File.AppendAllText(outputQuestionsFullPath, stringOut);

            for (int i = 0; i < fullDictionaryByAdvert.Length; i++)              //for each advert
            {
                for (int k = 0; k < fullDictionaryByAdvert[i].question.Count; k++)
                {
                    questionHolder += "," + fullDictionaryByAdvert[i].question[k];
                }
                stringOut = fullDictionaryByAdvert[i].identifier + "," + fullDictionaryByAdvert[i].adBlockStartLine + ","
 + (fullDictionaryByAdvert[i].adQuestionStartLine + fullDictionaryByAdvert[i].adBlockStartLine) + "," + (fullDictionaryBy
Advert[i].adQuestionEndLine + fullDictionaryByAdvert[i].adBlockStartLine) + questionHolder + "\n";
                System.IO.File.AppendAllText(outputQuestionsFullPath, stringOut);

                questionHolder = "";
            }
        }

        static void WriteWordAdvertOut()
        {
            string stringOut = "";
            string advertHolder = "";

            //Build header
```

```
            stringOut = "WORD,ADVERTS\n";
            System.IO.File.AppendAllText(outputByWordAdvertListingFullPath, stringOut);

            for (int i = 0; i < fullDictionaryByWord.Count; i++)        // for every word ...
            {
                for (int k = 0; k < fullDictionaryByWord[i].advertSources.Count; k++)      // for each advert entry withi
n ...
                {
                    advertHolder += "," + fullDictionaryByWord[i].advertSources[k];
                }
                stringOut = fullDictionaryByWord[i].wordText + advertHolder + "\n";
                System.IO.File.AppendAllText(outputByWordAdvertListingFullPath, stringOut);

                advertHolder = "";
            }
        }

        static void WriteWordAdvertOut_Excel()
        {
            //outputByWordAdvertListingFullPath_ExcelFriendly
            string stringOut = "";
            string advertHolder = "";

            //Build header
            stringOut = "WORD,ADVERTS\n";
            System.IO.File.AppendAllText(outputByWordAdvertListingFullPath_ExcelFriendly, stringOut);

            for (int i = 0; i < fullDictionaryByWord.Count; i++)        // for every word ...
            {
                for (int k = 0; k < fullDictionaryByWord[i].advertSources.Count; k++)      // for each advert entry withi
n ...
                {
                    advertHolder += fullDictionaryByWord[i].advertSources[k] + "/";
                }
                stringOut = fullDictionaryByWord[i].wordText + "," + advertHolder + "\n";
                System.IO.File.AppendAllText(outputByWordAdvertListingFullPath_ExcelFriendly, stringOut);

                advertHolder = "";
```

```
            }
        }
    }
}
```

10.6 Appendix 6. Chapter 4: Computer Code 4 – Highlight Words

```
using System;
using System.IO;
using System.Linq;
using System.Text.RegularExpressions;


// This program will (for each job advert file):
// 1- rename "ADVERT. TEXT START" as "ADVERT TEXT START" [not req., tag will be deleted @ #2b]
// 2- remove all the details by looking at tags [DONE]
//      a- must be aware of erroneously arranged tags (checked within FindErroneousAd) [DONE]
//      b- retain only the job advert identifier & job advert text [DONE]
// 3- substitute desired key words with {} versions [DONE]
// 4- export those rewritten job adverts [DONE]

// NOTE: to re-process files that have no tags (e.g. need to bracket more words), you need to:
//      - swap the declarations of 'tagsToRemove' (see Lines ~40-41)
//      - within ReplaceText(), blank the words you have already bracketed
//      - within ReplaceText(), add more RegEx lines to find the words you want bracketed (be sure to update the tags to
count in Coding #6)
//      - consider re-running the Coding #6 CountWords

namespace HighlightWords
{
    class Program
    {
        // FILE PATHS
        public static string inputFileList = @LocalPath;
        public static string outputFilePath = @LocalPath;

        // TRACKERS
        public static int currJobAd = 0;
        public static int currLine = 0;
        public static int totalJobs = 0;
```

```
        // PULLED DATA
        public static string currJobID;
        public static string[] jobList;
        public static string[] holdAdIn = new string[500]; // largest job is 181 lines; excess size
        public static string[] holdAdOut = new string[500];
        public static int jobTextStartLine = 0;
        public static int jobTextEndLine = 0;
        public static string[] tagsToRemove = new string[] { "*** JOB TITLE START ***", "*** JOB TITLE END ***", "*** COM
PANY START ***", "*** COMPANY END ***", "*** ADVERT. DATE START ***", "*** ADVERT. DATE END ***", "*** LOCATION START ***
", "*** LOCATION END ***", "*** SALARY START ***", "*** SALARY END ***", "*** PERMANENCY START ***", "*** PERMANENCY END
***", "*** INDUSTRY START ***", "*** INDUSTRY END ***", "*** QUESTIONS START ***", "*** QUESTIONS END ***" };
        //public static string[] tagsToRemove = new string[] { };

        static void Main(string[] args)
        {
            Console.WriteLine("Start");
            ListJobs(inputFileList);

            while (currJobAd < totalJobs)
            {
                // Read job in
                holdAdIn = File.ReadLines(jobList[currJobAd]).ToArray();

                // Do edits
                FindErroneousAd(holdAdIn);  // all erroneous files have been removed before final run
                holdAdOut = DeleteTags(holdAdIn);
                holdAdOut = ReplaceText(holdAdOut);


                // Save out
                WriteOut(holdAdOut, currJobID);

                // Loop
                Array.Clear(holdAdIn, 0, holdAdIn.Length);
                jobTextStartLine = 0;
                jobTextEndLine = 0;

                currJobAd++;
```

```
            }

            // END OF CODE
            Console.WriteLine();
            Console.WriteLine("Done. Press [enter] key ...");
            Console.ReadLine();
        }

        static void ListJobs(string listFile)
        {
            totalJobs = File.ReadLines(listFile).Count();   // get count
            jobList = new string[totalJobs];                // create array
            jobList = File.ReadLines(listFile).ToArray();   // import job ads paths into list
        }
        static void FindErroneousAd(string[] textIn)
        {
            jobTextStartLine = 0;
            jobTextEndLine = 0;

            jobTextStartLine = Array.LastIndexOf(textIn, "*** ADVERT. TEXT START ***");
            jobTextEndLine = Array.LastIndexOf(textIn, "*** ADVERT TEXT END ***");

            // If any job advert contains no text, display it
            if (jobTextEndLine <= jobTextStartLine) { Console.WriteLine(textIn[0]); }
        }
        static string[] DeleteTags(string[] textIn)
        {
            string[] textHold = new string[200];
            int textHoldWriteLocation = 0;
            string[] textOut;

            currJobID = textIn[0];

            // Find each tag and remove all lines between (and including of tags)
            for (int i = 0; i < tagsToRemove.Length; i += 2)
            {
                int tagStart = 0;
                int tagEnd = 0;
```

```
                tagStart = Array.LastIndexOf(textIn, tagsToRemove[i]);
                tagEnd = Array.LastIndexOf(textIn, tagsToRemove[i + 1]);

                // Error checks
                if (tagStart == -1 || tagEnd == -
1) { Console.WriteLine(textIn[0] + ": " + tagsToRemove[i] + " " + tagStart + " " + tagEnd); }
                if (tagStart == tagEnd) { Console.WriteLine(textIn[0]); }

                for (int j = tagStart; j < tagEnd; j++) { textIn[j] = ""; }
                textIn[tagEnd] = "";
            }

            // Copy out non-blank lines to temporary holder array
            for (int k = 0; k < textIn.Length; k++)
            {
                textIn[k] = textIn[k].Trim();
                // Skip any blank lines that are a part of the AdvertText
                if (textIn[k] != "" || (k > Array.LastIndexOf(textIn, "*** ADVERT. TEXT START ***") && k < Array.LastInde
xOf(textIn, "*** ADVERT TEXT END ***")))
                {
                    textHold[textHoldWriteLocation] = textIn[k];
                    textHoldWriteLocation++;
                }
            }

            // Create final write out string array
            if (Array.IndexOf(textHold, "*** ADVERT TEXT END ***") >= 0)     // if this tag is present then remove it, el
se skip past
            {
                textOut = new string[Array.LastIndexOf(textHold, "*** ADVERT TEXT END ***")];

                // Blank out final unnecessary lines
                textHold[Array.LastIndexOf(textHold, "*** ADVERT. TEXT START ***")] = "";
                textHold[Array.LastIndexOf(textHold, "*** ADVERT TEXT END ***")] = "";
            }
            else
            {
```

```
                textOut = new string[Array.IndexOf(textHold, null)];
                for (int i = 0; i < textOut.Length; i++)
                {
                    textOut[i] = textHold[i];
                }

            }

            // Write out from temp holder to final write array
            for (int i = 0; i < textOut.Length; i++) { textOut[i] = textHold[i]; }

            return textOut;
        }
        static string[] ReplaceText(string[] textIn)
        {
            Console.WriteLine("Replacing job ad #" + currJobAd);

            for (int i = 0; i < textIn.Length; i++)
            {
                #region Replacing words with {words}
                textIn[i] = Regex.Replace(textIn[i], @"\baccuracy\b", "{accuracy}", RegexOptions.IgnoreCase);
                // ...
                // accurately, act, acted, acting, acuity, acumen, adapt, adapted, adapting, analyse, analysed, analysing
, analyze, analyzed, analyzing, animate, animated, animating, applicable, applicably, apposite, appositely, appraise, app
raised, appraising, appreciation, approximate, approximately, arrange, arranged, arranging, assemble, assembled, assembli
ng, assess, assessed, assessing, aware, awareness, biased, biasedly, brief, briefed, briefing, broad, broadly, budget, bu
dgeted, budgeting, build, building, built, business sense, business-
sense, calculate, calculated, calculating, categorise, categorised, categorising, categorize, categorized, categorizing,
change, changed, changing, clarified, clarify, clarifying, clarity, classified, classify, classifying, clear, clearly, co
de, coded, coding, coherent, coherently, collect, collected, collecting, combine, combined, combining, compelling, compel
lingly, competence, competent, compile, compiled, compiling, complete, completed, completing, compose, composing, compreh
ensible, comprehensive, comprehensively, conceive, conceived, conceiving, conclude, concluded, concluding, congruent, con
gruently, conject, conjected, conjecting, considering implications, consolidate, consolidated, consolidating, construct,
constructed, constructing, construe, construed, construing, correct, correctly, correspond, corresponded, corresponding,
create, created, creating, credible, credibly, critique, critiqued, critiquing, crucial, crucially, cultivate, cultivated
, cultivating, debate, debated, debating, debug, debugged, debugging, decide, decided, deciding, decode, decoded, decodin
g, deduce, deduced, deducing, deep, deeply, defend, defended, defending, define, defined, defining, delete, deleted, dele
ting, depict, depicted, depicting, describe, described, describing, design, designed, designing, detect, detected, detect
```

```
ing, determine, determined, determining, develop, developed, developing, devise, devised, devising, diagnose, diagnosed,
diagnosing, dictate, dictated, dictating, discriminate, discriminated, discriminating, discuss, discussed, discussing, di
sprove, disproved, disproving, diverse, diversity, effects, elaborate, elaborated, elaborating, enhance, enhanced, enhanc
ing, equitable, equitably, essential, essentially, establish, established, establishing, estimate, estimated, estimating,
 evaluate, evaluated, evaluating, exact, exactly, examine, examined, examining, exchange, exchanged, exchanging, expand,
expanded, expanding, expertise, expertly, explain, explained, explaining, explicit, explicitly, extensive, extensively, f
acilitate, facilitated, facilitating, fairly, fairness, false, falsely, flawed, forecast, forecasted, forecasting, formul
ate, formulated, formulating, frame, framed, framing, gauge, gauged, gauging, generalise, generalised, generalising, gene
ralize, generalized, generalizing, generate, generated, generating, grade, graded, grading, hypothesise, hypothesised, hy
pothesising, hypothesize, hypothesized, hypothesizing, identified, identify, identifying, illogical, illogically, illustr
ate, illustrated, illustrating, imagine, imagined, imagining, impartial, impartially, implausible, implausibly, important
, importantly, improve, improved, improving, inapplicable, inapplicably, inclusive, inclusively, incorporate, incorporate
d, incorporating, incorrect, incorrectly, indistinct, indistinctly, inexact, inexactly, infer, inferred, inferring, initi
ate, initiated, initiating, insignificant, insignificantly, inspect, inspected, inspecting, integrate, integrated, integr
ating, intelligently, intelligible, interface, interfaced, interfacing, interpret, interpreted, interpreting, invent, inv
ented, inventing, investigate, investigated, investigating, irrational, irrationally, judge, judged, judging, just, justi
fied, justify, justifying, justly, limited, logic, logically, lucid, lucidly, made, make, making, manage, managed, managi
ng, mark, marked, marking, maximise, maximised, maximising, maximize, maximized, maximizing, meaningless, meaninglessly,
measure, measured, measuring, mediate, mediated, mediating, methodical, methodology, minimise, minimised, minimising, min
imize, minimized, minimizing, minor, model, modelled, modelling, modified, modify, modifying, multifarious, multiple solu
tions, name, named, naming, narrow, narrowly, negotiate, negotiated, negotiating, network, networked, networking, numerou
s, objective, objectively, obscure, obscurely, open minded, ordered, organisation, organise, organised, organising, organ
ization, organize, organized, organizing, originate, originated, originating, outline, outlined, outlining, overhaul, ove
rhauled, overhauling, partial, partially, perform, performed, performing, pinpoint, pinpointed, pinpointing, plan, planne
d, planning, portray, portrayed, portraying, precisely, precision, predict, predicted, predicting, predisposed, prepare,
prepared, preparing, prescribe, prescribed, prescribing, present, presented, presenting, prioritise, prioritised, priorit
ising, prioritize, prioritized, prioritizing, produce, produced, producing, proficiency, proficient, profound, profoundly
, program, programmed, programming, propose, proposed, proposing, prove, proved, proving, ramifications, rank, ranked, ra
nking, rate, rated, rating, rational, rationally, realise, realised, realising, realize, realized, realizing, rearrange,
rearranged, rearranging, recognise, recognised, recognising, recognize, recognized, recognizing, recommend, recommended,
recommending, reconcile, reconciled, reconciling, reconstruct, reconstructed, reconstructing, relate, related, relating,
relevance, relevantly, reorganise, reorganised, reorganising, reorganize, reorganized, reorganizing, repercussions, resea
rch, researched, researching, resolve, resolved, resolving, revise, revised, revising, rewrite, rewriting, rewritten, rig
ht, rough, roughly, score, scored, scoring, scrutinise, scrutinised, scrutinising, scrutinize, scrutinized, scrutinizing,
 select, selected, selecting, sensible, sensibly, serious, seriously, set up, setting up, setting-up, set-
up, several, shallow, show, showing, shown, significance, significantly, solve, solved, solving, sound, soundly, specific
, specifically, specified, specify, specifying, state, stated, stating, strategic, strategically, structure, structured,
subjective, subjectively, substitute, substituted, substituting, suitable, suitably, summarise, summarised, summarising,
```

```
summarize, summarized, summarizing, superficial, superficially, support, supported, supporting, suppose, supposed, suppos
ing, synthesise, synthesised, synthesising, synthesize, synthesized, synthesizing, systematic, systematicity, taught, tea
ch, teaching, tell, telling, test, testing, theorise, theorised, theorising, told, translate, translated, translating, tr
ivial, trivially, truth, truthfully, unbiased, unbiasedly, unconnected, unconnectedly, unfitting, unfittingly, unified, u
nify, unifying, unimportant, unimportantly, unjustifiable, unjustifiably, unprejudiced, unreasonable, unreasonably, unrel
ated, unrelatedly, upheld, uphold, upholding, vague, vaguely, validate, validated, validating, value, valued, valuing, va
rious, verified, verify, verifying, write, writing, written, wrong
                // ...
                textIn[i] = Regex.Replace(textIn[i], @"\bwrongly\b", "{wrongly}", RegexOptions.IgnoreCase);
                #endregion

                #region CT literal phrases // replace "solving" with extended phrases as appropriate. Note the lack of '\
b' near parenthesis
                textIn[i] = Regex.Replace(textIn[i], @"\bproblem {solving}", "{problem solving}", RegexOptions.IgnoreCase
);
                // ...
                // problem-solving, problem solve, problem-
solve, solve problem, solve problems, solving problem, solving problems, critical thinking, analytical thinking, proactiv
e thinking, forward thinking, innovative thinking, lateral thinking, troubleshooting, trouble shooting, trouble-
shooting, critical reasoning, think critically, reason critically, decision-making, decision making, decision-
make, decision-make, business awareness, business-awareness, business aware
                // ...
                textIn[i] = Regex.Replace(textIn[i], @"\bbusiness-{aware}", "{business-aware}", RegexOptions.IgnoreCase);
                #endregion

                #region position description phrases
                textIn[i] = Regex.Replace(textIn[i], @"\bposition description\b", "[[position description]]", RegexOption
s.IgnoreCase);
                // ...
                // more information, more info, more info., more details, further information, further info, further info
., further details
                // ...
                textIn[i] = Regex.Replace(textIn[i], @"\brole statement\b", "[[role statement]]", RegexOptions.IgnoreCase
);

                #endregion

                #region noun forms
                textIn[i] = Regex.Replace(textIn[i], @"\badaptation\b", "<<adaptation>>", RegexOptions.IgnoreCase);
```

```
                // ...
                // analysis, assembly, assessment, bias, breadth, calculation, categorisation, categorization, collection
, combination, compilation, completion, composition, concept, conclusion, conjecture, consideration, consolidation, const
ruction, correspondence, creation, credibility, critique, decisions, deduction, defence, defense, definition, deletion, d
epiction, depth, description, detection, determination, development, diagnosis, dictation, discrimination, discussion, en
hancement, establishment, estimation, evaluation, examination, expansion, explanation, facilitation, generation, hypothes
is, identification, illustration, imagination, implementation, importance, improvement, incorporation, indistinction, inf
erence, interpretation, invention, investigation, judgement, justification, management, measurement, mediation, modificat
ion, negotiation, performance, portrayal, prediction, predisposition, preparation, prescription, proof, proposal, ramific
ation, recommendation, reconciliation, reconstruction, reorganisation, repercussion, resolution, scrutiny, selection, sig
nificant, solution, specification, statement, summary, supposition, synthesis, theory, translation, unification, validati
on, verification
                // ...
                textIn[i] = Regex.Replace(textIn[i], @"\bcritical thinker\b", "<<critical thinker>>", RegexOptions.Ignore
Case);
                #endregion

                textIn[i] = Regex.Replace(textIn[i], @"\bnot\b", "||not||", RegexOptions.IgnoreCase);
            }

            return textIn;
        }
        static void WriteOut(string[] textOut, string labelOut)
        {
            string outputPath = outputFilePath + labelOut;
            System.IO.File.WriteAllLines(outputPath, textOut);
        }
    }
}
```

10.7 Appendix 7. Chapter 4: Computer Code 5 – Count Words

```
using System;
using System.IO;
using System.Linq;

// This program will (for each job advert file with bracketed key words):
// 1- identify double tags for further investigation    [DONE]
// 2- count each of the desired bracketed words         [DONE]
// 3- write the count of the bracketed words on to the bottom of each file  [DONE]
//      a- delete EOF blank lines [DONE]
// 4- export each file      [DONE]
// 5- export summary CSV of job ads and counts of each word     [DONE]

// NOTE: to create only the summary CSV file;
//      - comment out "WriteOut()" on ~line 75
//      - ensure that "WriteOutSummary()" is active (~line 84)

namespace CountWords
{
    class Program
    {
        // FILE PATHS
        public static string inputFileList = @LocalPath;
        //public static string inputFileList = @LocalPath;
        public static string outputFilePath = @LocalPath;

        // TRACKERS
        public static int currJobAd = 0;
        public static int currAdLength = 0;
        public static int totalJobs = 0;
        public static int numCountWords = 0;

        // PULLED DATA
        public static string currJobID;
        public static bool jobAlreadyCounted;
```

```
        public static string[] pathToJobs;
        public static string[] holdAdIn = new string[200]; // largest job is <100 lines; excess size
        public static string[] holdAdOut;   // the fullest array to take all ad text and all counted words
        public static string[] holdAdWriteOut;  // the reduced array of the above

        public static string[] bracketWords = new string[] { "{accuracy}", ..., "<<critical thinker>>", "{}", "[[]]", "<<
>>" };

        public static string[] jobList;
        public static int[,] fullWordCount;
        public static int[] tempWordCount;

        static void Main(string[] args)
        {
            Console.WriteLine("Start");
            ListJobs(inputFileList);

            // create array to hold the ID of each job
            jobList = new string[pathToJobs.Length];
            // create array to hold the count of each word for each job
            numCountWords = bracketWords.Length;
            fullWordCount = new int[totalJobs, numCountWords];


            while (currJobAd < totalJobs)
            {
                // Read job in
                holdAdIn = File.ReadLines(pathToJobs[currJobAd]).ToArray();
                currAdLength = File.ReadLines(pathToJobs[currJobAd]).Count();
                currJobID = holdAdIn[0];
                jobList[currJobAd] = currJobID;

                holdAdOut = new string[currAdLength + bracketWords.Length + 2];     // extra 2 lines for line break and a
 header

                tempWordCount = new int[numCountWords];

                // Check for double brackets and check for pre-counted
```

```
            PreliminaryCheck(holdAdIn);   // checked for brackets, no errors present

            // Count the desired words and append to file
            CountWords(holdAdIn);

            // Save out each file
            WriteOut(holdAdWriteOut, currJobID);

            // Loop
            Array.Clear(holdAdIn, 0, holdAdIn.Length);
            Console.WriteLine("Processing job " + currJobAd);
            currJobAd++;
        }

        // Save out summary file
        WriteOutSummary();

        // END OF CODE
        Console.WriteLine();
        Console.WriteLine("Done. Press [enter] key ...");
        Console.ReadLine();
    }

    static void ListJobs(string listFile)
    {
        totalJobs = File.ReadLines(listFile).Count();   // get count
        pathToJobs = new string[totalJobs];               // create array
        pathToJobs = File.ReadLines(listFile).ToArray();  // import job ads paths into list
    }

    static void PreliminaryCheck(string[] textIn)
    {
        int hasCountedHeader = 0;

        foreach (string s in textIn)
        {
            bool existsOpen = s.Contains("{{");
            bool existsClose = s.Contains("}}");
```

```
                bool existsTripleOpen = s.Contains("[[[");
                bool existsTripleClose = s.Contains("]]]");

                if (s == "***COUNT DATA***") { hasCountedHeader++; }
                if (existsOpen || existsClose) { Console.WriteLine(currJobID + " {{ or }} issue"); }
                if (existsTripleOpen || existsTripleClose) { Console.WriteLine(currJobID + " [[[ or ]]] issue"); }
            }

            if (hasCountedHeader > 0) { jobAlreadyCounted = true; } else { jobAlreadyCounted = false; }
        }

        static void CountWords(string[] textIn)
        {
            int endReadLine;
            int currentLastLine = textIn.Length;
            int countWrittenLines = 0;

            if (jobAlreadyCounted) { endReadLine = Array.IndexOf(textIn, "***COUNT DATA***"); }
            else
            {
                // Find EOF blank lines
                int countBlankLines = 0;
                for (int i = textIn.Length; i-- > 0;)   // loop backwards
                {
                    if (textIn[i] == "") { countBlankLines++; }
                    else { break; }
                }

                currentLastLine -= countBlankLines; // update apparent EOF having ignored the blank lines
                endReadLine = currentLastLine;
            }

            for (int i = 0; i < endReadLine; i++)
            {
                // take each line and count bracket word instances
                for (int j = 0; j < bracketWords.Length; j++)
                {
                    if (textIn[i].Contains(bracketWords[j]))
```

```
                    {
                        fullWordCount[currJobAd, j]++;
                        tempWordCount[j]++;
                    }
                }
                // write that line to the output
                holdAdOut[i] = textIn[i];
            }

            // if already counted, be sure to write those extra lines
            if (endReadLine < currentLastLine)
            {
                for (int i = endReadLine; i < currentLastLine; i++)
                {
                    holdAdOut[i] = textIn[i];
                }
            }

            if (!jobAlreadyCounted)
            {
                holdAdOut[endReadLine] = "";
                holdAdOut[endReadLine + 1] = "***COUNT DATA***";
                currentLastLine++;
                currentLastLine++;
            }

            for (int i = 0; i < bracketWords.Length; i++)
            {
                if (tempWordCount[i] == 0) { currentLastLine--
; } // checked, program does not overwrite in case of multiple skipped words
                else
                {
                    holdAdOut[i + currentLastLine] = bracketWords[i] + " " + tempWordCount[i];
                    countWrittenLines++;
                }
            }

            // create new array of appropriate size & write out
```

```
            holdAdWriteOut = new string[endReadLine + countWrittenLines + 2]; // plus 2 header lines
            for (int i = 0; i < holdAdWriteOut.Length; i++) { holdAdWriteOut[i] = holdAdOut[i]; }
        }

        static void WriteOut(string[] textOut, string labelOut)
        {
            string outputPath = outputFilePath + labelOut;
            System.IO.File.WriteAllLines(outputPath, textOut);
        }

        static void WriteOutSummary()
        {
            string outputPath = outputFilePath + "SummaryCount.csv";
            string headerLine;
            string totalLine;
            string holderLine;

            // Calculate total count of each word
            int[] totalCountWord = new int[bracketWords.Length];

            Console.WriteLine("Calculating total of each word");
            for (int i = 0; i < bracketWords.Length; i++)
            {
                for (int j = 0; j < totalJobs; j++)
                {
                    //Going through array vertically
                    totalCountWord[i] += fullWordCount[j, i];
                }
            }

            // Calculate total count of each job
            int[] totalCountJob = new int[totalJobs];

            Console.WriteLine("Calculating total words per job");
            for (int i = 0; i < totalJobs; i++)
            {
                for (int j = 0; j < bracketWords.Length; j++)
                {
```

```
                //Going through array horizontally
                totalCountJob[i] += fullWordCount[i, j];
            }
        }

        // Calculate unique count of each job
        int[] totalUCountJob = new int[totalJobs];

        Console.WriteLine("Calculating unique words per job");
        for (int i = 0; i < totalJobs; i++)
        {
            for (int j = 0; j < bracketWords.Length; j++)
            {
                //Going through array horizontally
                if (fullWordCount[i, j] > 0) { totalUCountJob[i]++; }
                //totalUCountJob[i] += fullWordCount[j, i];
            }
        }

        Console.WriteLine("Begin writing array");
        // Create total line
        totalLine = "TOTAL,";
        totalLine += string.Join(",", totalCountWord);
        totalLine += ",TOTAL (" + totalCountWord.Sum() + "),Uniques";
        totalLine += "\r\n";
        System.IO.File.WriteAllText(outputPath, totalLine);

        // Create header line CSV
        headerLine = "Name,";
        headerLine += string.Join(",", bracketWords);
        headerLine += ",Total,Uniques,\r\n";
        System.IO.File.AppendAllText(outputPath, headerLine);

        // Create count lines
        Console.WriteLine("Writing out job lines");
        for (int i = 0; i < totalJobs; i++)
        {
            //Console.WriteLine("Writing out job line " + i++);
```

```
                holderLine = jobList[i] + ",";

                for (int j = 0; j < bracketWords.Length; j++)
                {
                    holderLine += (fullWordCount[i, j] + ",");
                }
                holderLine += totalCountJob[i] + ",";
                holderLine += totalUCountJob[i];
                holderLine += "\r\n";
                System.IO.File.AppendAllText(outputPath, holderLine);
            }
        }
    }
}
```

10.8 Appendix 8. Chapter 6: Review of critical thinking tests

The following tables detail the reviewed critical thinking tests. Table 10-2 (pg. 257) lists the test provider and a link to the test details. Table 10-3 (pg. 262) outlines the test specifics. Some tests were found from an online list (Ennis & Chattin, 2015).

Table 10-2. List of reviewed critical thinking tests, including name, provider and URL. Accessed March 2018.

Test Name	Provider Name	Provider Website	Other Test Link
ACER Test of Abstract Reasoning (TAR)	ACER	https://www.acer.org	https://shop.acer.edu.au/acer-test-of-abstract-reasoning-acer-tar
ACT CAAP Test: Critical Thinking	American College Testing - College Assessment of Academic Proficiency	http://www.act.org/content/act/en/products-and-services/act-collegiate-assessment-of-academic-proficiency/test-prep.html#CriticalThinkingTest	http://www.act.org/content/act/en/products-and-services/act-collegiate-assessment-of-academic-proficiency/test-prep.html#CriticalThinkingTest
ACT Science Reasoning	American College Testing - College Assessment of Academic Proficiency		http://www.actstudent.org/testprep/descriptions/scidescript.html
Aptitude for Engineering and Computer Science Assessment	ACER	https://www.acer.org	https://www.acer.org/aea
Australian Law Schools entrance test	ACER	https://www.acer.org	https://www.acer.org/alset
Business Attribute Inventory	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Attributes-Tests/Business-Attribute-Inventory-BAI
Business CTST	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Business-Critical-Thinking-Skills-Test-BCTST

Test Name	Provider Name	Provider Website	Other Test Link
Business CTST-N	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Business-Critical-Thinking-Skills-Test-Numeracy-BCTST-N
Business Select	ACER	https://www.acer.org	https://www.acer.org/business-select
California CTST	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/California-Critical-Thinking-Skills-Test-CCTST
California CTST-N	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/California-Critical-Thinking-Skills-Test-Numeracy-CCTST-N
Cambridge Thinking Skills Assessment	Cambridge Assessment		http://www.admissionstests.cambridgeassessment.org.uk/adt/tsacambridge/about
CCTDI	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Attributes-Tests/California-Critical-Thinking-Disposition-Inventory-CCTDI
CCT-G835	Insight Assessment	https://www.insightassessment.co	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/CCT-G835
CLA+	CAE	http://cae.org	http://cae.org/flagship-assessments-cla-cwra/cla/assessment-design-and-sample/
CLA+ International	CAE	http://cae.org	http://cae.org/flagship-assessments-cla-cwra/flagship-assessments-cla-cwra/learn-more-about-cla-international
Cornell Class Reasoning Test	Cornell	http://www.criticalthinking.net/testing.html	http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=ED003818
Cornell Conditional Reasoning Test	Cornell	http://www.criticalthinking.net/testing.html	http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=ED003818

Test Name	Provider Name	Provider Website	Other Test Link
Cornell CT Test Level X	Cornell	http://www.criticalthinking.com	http://www.criticalthinking.com/cornell-critical-thinking-test-level-x.html
Cornell CT Test Level Z	Cornell	http://www.criticalthinking.com	http://www.criticalthinking.com/cornell-critical-thinking-test-level-z.html
Critical Thinking Reading and Writing Test	CriticalThinking.org	http://www.criticalthinking.org	http://www.criticalthinking.org/store/products/the-international-critical-thinking-reading-and-writing-test/257
Critical Thinking: Concepts and Understandings	CriticalThinking.org	http://www.criticalthinking.org	http://www.criticalthinking.org/pages/online-critical-thinking-basic-concepts-test/679
Ennis-Weir Critical Thinking Essay Test	Ennis-Weir	http://www.criticalthinking.net	http://faculty.education.illinois.edu/rhennis/tewctet/Ennis-Weir_Merged.pdf
ETS Proficiency Profile (formerly MAPP)	Educational Testing Service, Princeton		http://www.ets.org/proficiencyprofile/about
GAMSAT	ACER	https://www.acer.org	https://gamsat.acer.org/
GMAT Critical Reasoning	GMAT		http://www.majortests.com/gmat/critical_reasoning.php
Health Sciences Reasoning Test	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Health-Sciences-Reasoning-Test-HSRT
HSRT-Associate Degree	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Health-Science-Reasoning-Test-Associate-Degree-HSRT-AD
HSRT-N	Insight Assessment	https://www.insightassessment.com/	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Health-Sciences-Reasoning-Test-Numeracy-HSRT-N
ICAT Critical Thinking Essay Test	Center for Critical Thinking and Moral Critique	http://www.criticalthinking.org	http://www.criticalthinking.org/pages/international-critical-thinking-test/619

Test Name	Provider Name	Provider Website	Other Test Link
Legal Studies Reasoning Profile	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Legal-Studies-Reasoning-Profile-LSRP
Military and Defense Critical Thinking Disposition Inventory	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Military-and-Defense-Critical-Thinking-Inventory-MDCTI
MyThinkingStyles	Pearson - TalentLens	http://www.thinkwatson.com	http://www.thinkwatson.com/mythinkingstyles
Oxford Thinking Skills Assessment	Cambridge Assessment		http://www.admissionstests.cambridgeassessment.org.uk/adt/tsaoxford/about
Quant-Q	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Quant-Q-Measure-Quantitative-Reasoning
Seeking Critical Thinkers	ACER	https://www.acer.org	https://www.acer.org/sct
Talent Assessment (formerly: SHL Critical Reasoning Test Battery)	CEBGlobal		https://www.cebglobal.com/shldirect/en/assessment-advice/example-questions
Tasks in Critical Thinking	Educational Testing Service, Princeton	https://www.ets.org	https://www.ets.org/heighten/about/critical_thinking/
TER-N	Insight Assessment	https://www.insightassessment.com/	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Test-of-Everyday-Reasoning-Numeracy-TER-N
Test of Everyday Reasoning (TER)	Insight Assessment	https://www.insightassessment.co	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Test-of-Everyday-Reasoning-TER

Test Name	Provider Name	Provider Website	Other Test Link
Test of Problem Solving 2 Adolescent (TOPS2)	LinguiSystems		http://www.linguisystems.com/products/product/display?itemid=10440
Test of Problem Solving 3 Elementary (TOPS3)	LinguiSystems		http://www.linguisystems.com/products/product/display?itemid=10362
The Critical Thinking Assessment Test (CAT)	Center for Assessment and Improvement of Learning		http://www.tntech.edu/cat/
Transfer and ReEntry Adult Assessment	Insight Assessment	https://www.insightassessment.com	https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/Transfer-and-Re-Entry-Adult-Assessment-TRAA
UMAT	ACER	https://www.acer.org	https://umat.acer.edu.au/
Watson & Glaser	Pearson - TalentLens	http://www.thinkwatson.com	http://www.thinkwatson.com/assessments/watson-glaser
Watson-Glaser II Critical Thinking Appraisal	Pearson - TalentLens	http://us.talentlens.com	http://us.talentlens.com/watson-glaser-critical-thinking-test

Table 10-3. List of reviewed critical thinking tests, including name, duration, modality, and elements tested. Accessed March 2018.

Test Name	Duration (min)	Mode (*e.g.* multiple-choice question)	Elements tested
ACER Test of Abstract Reasoning (TAR)	25	multiple-choice question	abstract reasoning
ACT CAAP Test: Critical Thinking	40	multiple-choice question	argument analysis, argument evaluation, argument extension
ACT Science Reasoning	40	multiple-choice question	data representation, research summaries, conflicting viewpoints
Aptitude for Engineering and Computer Science Assessment	150	multiple-choice question	quantitative, critical, scientific, and interpersonal reasoning
Australian Law Schools entrance test	130	multiple-choice question	critical thinking, understanding, analysis
Business Attribute Inventory	25	multiple-choice question	dependability, job commitment, honesty, desire to work, desire to learn, desire to think, workplace flexibility, professionalism, workplace tolerance
Business CTST	60	multiple-choice question	analysis, inference, evaluation, induction, deduction, and overall reasoning skills
Business CTST-N		multiple-choice question	analysis, interpretation, inference, evaluation, explanation, induction, deduction, and overall reasoning skills plus numeracy
Business Select	120	multiple-choice question	comprehension, analysis, synthesis, evaluation of arguments
California CTST	50	multiple-choice question	analysis, evaluation, inference, deduction, induction and overall reasoning skills, interpretation, explanation
California CTST-N		multiple-choice question	analysis, evaluation, inference, deduction, induction and overall reasoning skills, interpretation, explanation, numeracy
Cambridge Thinking Skills Assessment	90	multiple-choice question	problem-solving skills, including numerical and spatial reasoning. critical thinking skills, including understanding argument and reasoning using everyday language.

Test Name	**Duration (min)**	**Mode (*e.g.* multiple-choice question)**	**Elements tested**
CCTDI	30	multiple-choice question	truth-seeking, open-mindedness, toward anticipating possible consequences or being heedless of them, systematicity, confidence in reasoning, inquisitiveness, maturity of judgement
CCT-G835	60	multiple-choice question	analytical skills, inference skills, evaluative skills, inductive reasoning skills and deductive reasoning skills
CLA+	90	multiple-choice question, essay	analysis, problem solving, scientific reasoning, quantitative reasoning, critical reading, critical evaluation, critiquing an argument
CLA+ International	90	multiple-choice question, essay	analysis, problem solving, scientific reasoning, quantitative reasoning, critical reading, critical evaluation, critiquing an argument
Cornell Class Reasoning Test		multiple-choice question	deductive reasoning
Cornell Conditional Reasoning Test		multiple-choice question	deductive reasoning
Cornell CT Test Level X	50	multiple-choice question	induction, deduction, credibility, assumptions
Cornell CT Test Level Z	50	multiple-choice question	induction, deduction, credibility, assumptions, semantics, predictions
Critical Thinking Reading and Writing Test		short answer	clarify purposes, formulate clear questions, distinguish accurate and relevant information from inaccurate and irrelevant information, reach logical inferences or conclusions, identify significant and deep concepts, distinguish justifiable from unjustifiable assumptions, trace logical implications
Critical Thinking: Concepts and Understandings	45	multiple-choice question	analysis, assessment, disposition, and skills and abilities of thought
Ennis-Weir Critical Thinking Essay Test			reasons, assumptions, alternative explanations, fallacies

Test Name	**Duration (min)**	**Mode (*e.g.* multiple-choice question)**	**Elements tested**
ETS Proficiency Profile (formerly MAPP)	120	multiple-choice question	distinguish between rhetoric and argumentation in a piece of nonfiction prose, recognize assumptions, recognize the best hypothesis to account for information presented, infer and interpret a relationship between variables, draw valid conclusions based on information presented
GAMSAT	355	multiple-choice question, essay	reasoning and communication
GMAT Critical Reasoning	210	multiple-choice question, essay	analysis of argument, multi-source reasoning, graphics interpretation, two-part analysis, table analysis, data sufficiency, problem solving, reading comprehension, critical reasoning, sentence correction
Health Sciences Reasoning Test	50	multiple-choice question	analysis, inference, evaluation, induction and deduction
HSRT-Associate Degree	50	multiple-choice question	analysis, inference, evaluation, induction, deduction and numeracy
HSRT-N		multiple-choice question	analysis, inference, evaluation, induction and deduction, numeracy
ICAT Critical Thinking Essay Test		short answer	identifying purpose, question at issue, information, conclusions, assumptions, concepts, implications, point of view. pointing out strengths and possible limitations and/or weaknesses of the reasoning in the writing sample
Legal Studies Reasoning Profile	90	multiple-choice question	mental focus, intellectual integrity, mental rigor, foresight, cognitive maturity, professional confidence, communicative confidence, teamwork, peer expression, directness. overall reasoning skills, analysis, inference, evaluation, deduction, induction
Military and Defense Critical Thinking Disposition Inventory	90	multiple-choice question	communicative confidence, professional confidence, peer expression, teamwork, directness, intellectual integrity mental focus, mental rigor, foresight, and cognitive maturity. overall score and scores on five more specific reasoning skills: analysis, inference, evaluation, deduction and induction.
MyThinkingStyles	10	multiple-choice question	analytical, inquisitive, insightful, open-minded, systematic, timely, and truth-seeking thought processes

Test Name	Duration (min)	Mode (*e.g.* multiple-choice question)	Elements tested
Oxford Thinking Skills Assessment	120	multiple-choice question, essay	problem-solving skills, including numerical and spatial reasoning. critical thinking skills, including understanding argument and reasoning using everyday language.
Quant-Q	50	multiple-choice question	pattern recognition, probability combinatorics, out-of-the-box algebra, geometry and optimization and quant q overall
Seeking Critical Thinkers	45	multiple-choice question	comprehension, analysis, synthesis, evaluation of arguments, evaluate evidence
Talent Assessment (formerly: SHL Critical Reasoning Test Battery)			verbal reasoning, numerical reasoning, inductive reasoning, checking, calculation, personality questionnaire, motivation questionnaire, situational judgement
Tasks in Critical Thinking			evaluating evidence, analysing and evaluating arguments
TER-N		multiple-choice question	analysis, interpretation, inference, evaluation, explanation, induction, deduction and reasoning skills overall plus numeracy.
Test of Everyday Reasoning (TER)	45	multiple-choice question	analysis, inference, evaluation, induction and deduction
Test of Problem Solving 2 Adolescent (TOPS2)	40	multiple-choice question, performance	understanding/comprehension, analysis, interpretation, self-regulation, evaluation, explanation, inference, insight, decision-making, intent/purpose, problem solving, acknowledgment, making inferences, determining solutions, problem solving, interpreting perspectives, and transferring insights
Test of Problem Solving 3 Elementary (TOPS3)	35	multiple-choice question, performance	making inferences, sequencing, negative questions, problem solving, predicting, determining causes.
The Critical Thinking Assessment Test (CAT)	60	essay	evaluating information, inferences, numerical relationships, evaluating evidence, interpreting data, using evidence to construct and evaluate arguments

Test Name	**Duration (min)**	**Mode (*e.g.* multiple-choice question)**	**Elements tested**
Transfer and ReEntry Adult Assessment	80	multiple-choice question	motivation to learn, drive to succeed, judgment, intellectual integrity, foresight, resilience and creativity. analytical reasoning, evaluative reasoning, quantitative reasoning, reasoning in uncertainty, and reasoning with precision.
UMAT	190	multiple-choice question	logical reasoning, problem solving, understanding people, non-verbal reasoning
Watson & Glaser		multiple-choice question	inferences, assumptions, deductions, interpretations and evaluation of arguments
Watson-Glaser II Critical Thinking Appraisal	40	multiple-choice question	recognise assumptions, evaluate arguments, draw conclusions

10.9 Appendix 9. Chapter 6: Industry face and context validation focus group

FOCUS GROUP COLLECTION FORM

Group 6 Industry – Focus Group Session

Background

Company: ______________________________

Date/Time: ______________________________

Number of Participants: ________________

1. Has this company hired graduates of the Monash B.PharmSci course or B.Eng(Chem) course in the past 5 years?

2. How long have you been working in industry?

3. How long have you been working at this company?

4. Do you work (or have you worked) in any of the roles that a graduate of the B.PharmSci or B.Eng (Chem) courses would typically fill within 1-2 years of their graduation? How long did you work in such a role?

5. Do you supervise (or have you supervised) any of the roles that a graduate of the B.PharmSci or B.Eng (Chem) courses would typically fill within 1-2 years of their graduation? How long did you work in such a role?

Validation Questions

6. Do the auxiliary documents accurately reflect the type of documents that would be found in your company?

7. Are these questions broadly reflective of the type/depth/style of problem that a graduate from the B.PharmSci would experience in their first 1-2 years in your company?

8. What other questions could perhaps address those metrics?

10.10 Appendix 10. Chapter 6: Monash businessThink (version 7)

TEST BOOKLET

Version 7 – "Answer revise"

BUSINESSTHINK : MEASURING INDUSTRY CRITICAL ABILITIES

(Pharmaceutical Sciences)

MONASH University
Pharmacy and Pharmaceutical Sciences

Closed-Response

VERSION 7 - INSTRUCTIONS

Thank you for taking your time to complete this Critical Thinking test. The test is currently at the stage of getting feedback from successful and academically-talented students. This will help us benchmark the final test.

- Your feedback is invaluable to developing and refining this test, so we are keen to get any notes (hand-written or electronic) that you make.

- Although this test is targeted at pharmaceutical scientists, we are confident that you can complete this test as no prior knowledge is required.

How to complete the test:

- This test is divided into **seven sections** (18 questions). You may complete each **section** separately. You do not have to do the entire test in one sitting.

- Each **section** has related handouts that should be used to answer the questions within that section.

- At the end of each section you will be asked to estimate how long each question took to complete and whether you made any notes.

Section 7 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
18	
19	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
18		
19		

- NOTE: You are strongly encouraged to use spare paper, calculator, or a computer/laptop when you are solving these questions.

- Once completed, make sure that you return: (i) consent form, (ii) completed test paper, and (iii) any electronic notes you made to: <<researcher email>>

BUSINESSTHINK : MEASURING INDUSTRY CRITICAL ABILITIES

MONASH University
Pharmacy and Pharmaceutical Sciences

Monash Student Number:

Demographics	**Your Response**	
Course		
ATAR/ENTER		
WAM		
Year started current degree		
Have you previously undertaken aptitude tests? (*e.g.* UMAT, GAMSAT, logical reasoning, verbal reasoning, numeric reasoning, California critical thinking tests, *etc.*)	Yes	No
In the past 6 months, have you prepared or trained for aptitude tests by:		
• completing sample tests,	Yes	No
• completing actual tests,	Yes	No
• tutoring/teaching others to complete these tests?	Yes	No
During your undergraduate course, have you undertaken an industry placement?	Yes	No

TEST INSTRUCTIONS

In this test you will take on the role as a **Graduate Pharmaceutical Scientist** at **Corporation Inc.** You will be given questions and challenges to test your industry-based critical thinking skills. For the purposes of this test you should only use the information provided in the test booklet and test handouts.

- This test is designed to reflect the types of questions you would be asked in industry.
- No prior knowledge is required.
- NOTE: You are strongly encouraged to use spare paper, calculator, or a computer/laptop when you are solving these questions.
- **Bolded** words are keywords, while underlined words are key instructions and key notes.

- Each section is standalone. No information crosses between sections.
- You should read all the questions in a given section before attempting that section.

Welcome to Corporation Inc. Your letter of acceptance is awaiting you…

Corp. Inc.
40 Thames Reach
Barking IG11 0HZ, UK

01/03/2022

To Whom It May Concern,

Congratulations on being hired as a **Graduate Pharmaceutical Scientist** at **Corporation Inc.** As a graduate, you will be working in both the **Formulation Department** and the **Quality Control Department**. Your job is to assist in the day-to-day running of these departments. Just like a normal job, your manager will periodically assign you tasks to complete.

These tasks are presented as questions below.

Like any real job, you will be dealing with a lot of information when making your decisions. Most questions will refer to specific handout documents that you must use when answering the questions.

Welcome to the team!

Best regards,

Section 1

Estimated time: 30 minutes

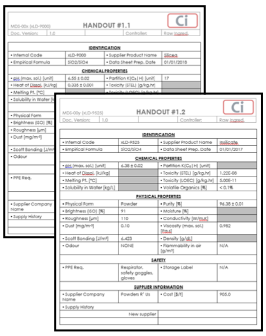
The **Formulation Department** at Corporation Inc. is responsible for developing new products. A large amount of time is spent on running tests and collecting data. These data are recorded on material data sheets. You are responsible for the routine testing of samples and collecting data.

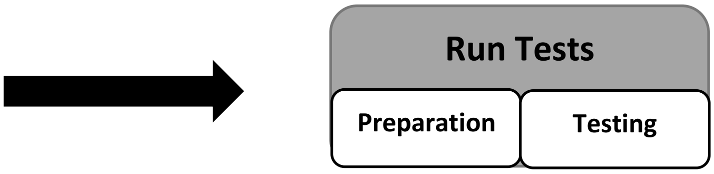
Your manager asks you to collect data on a powder sample. You receive a partially completed data sheet. You will need to plan how you will collect the missing data for your manager.

You should be aware that:

- Each test will give you one or more results.
- Some testing machines very delicate. They can only handle **liquids** or **powders**. Other machines can handle **slurries** or **emulsions**.

Carefully read **Section 1** and **Section 2** of each test protocol (TES-001 – TES-009).





MDS-00x (your data sheet)
carefully
MDS-00y (colleague's data sheet)

Plan how to collect missing data!
durations

Read test instructions

Select required tests
Plan and schedule your tests
Take note of costs and

At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(1) Question 1

You will need:

- **Handout #1.1 (MDS-00x)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**

The missing data is indicated on MDS-00x as greyed-out cells. You will need to plan how you will collect these data.

You want to collect the data using the least number of tests. Which test(s) should you undertake?

Tick the box corresponding with the test(s) you would undertake.

Test	Test Name	Handout Number	Tick Box
TES-001	pH Test	2.1	
TES-002	Solubility Test	2.2	
TES-003	Drying Test	2.3	
TES-004	Optical Test	2.4	
TES-005	Dissolution Test	2.5	
TES-006	Powder Flow Test	2.6	
TES-007	Stability Test	2.7	
TES-008	Slurry Test	2.8	
TES-009	Dry Powder Test	2.9	

Number of tests you would do: _______________

(2) Question 2

You will need:

- **Handout #1.1 (MDS-00x)**
- **Handouts #2.4, #2.6, #2.8 (TES-004, TES-006, TES-008)**
- **Handout #3.1 (BOO-001)**

Due to budget and time constraints, you manager now wants you to do only the following tests:

- TES-004,
- TES-006, and
- TES-008.

You will need to use the booking calendar (BOO-001) to book the equipment required for your tests.

Carefully read **Section 5** of each test protocol (TES-001 – TES-009), and take note of any steps that tell you "*Must wait for … minutes*". During these times you may be able to run other tests.

Starting at 9 AM on Monday morning, what is the earliest day and time on which the test(s) can be completed?

DAY: _______________

FINISH TIME: _______________

(3) Question 3

You will need:

- **Handout #1.2 (MDS-00y)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**

Some weeks later your manager asks you to finish some work that your colleague had started. You need to determine which tests need to be undertaken to collect the missing data.

What is the CHEAPEST (lowest cost) set of test(s) you could undertake to collect the missing data for their data sheet? Tick the box corresponding with the test(s) you would undertake.

Test	Test Name	Handout Number	Tick Box
TES-001	pH Test	2.1	
TES-002	Solubility Test	2.2	
TES-003	Drying Test	2.3	
TES-004	Optical Test	2.4	
TES-005	Dissolution Test	2.5	
TES-006	Powder Flow Test	2.6	
TES-007	Stability Test	2.7	
TES-008	Slurry Test	2.8	
TES-009	Dry Powder Test	2.9	

Indicate the combined cost and the total number of hours that the test(s) will take. You do not need to consider the booking times for this/these test(s).

COST: $_______________

TOTAL TIME: _______________ minutes

(4) Question 4

You will need:

- **Handout #1.2 (MDS-00y)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**

Now, looking at the same colleague's data sheet, what is the QUICKEST (shortest duration) test(s) you could undertake to collect the missing data for their data sheet? Tick the box corresponding with the test(s) you would undertake.

Test	Test Name	Handout Number	Tick Box
TES-001	pH Test	2.1	
TES-002	Solubility Test	2.2	
TES-003	Drying Test	2.3	
TES-004	Optical Test	2.4	
TES-005	Dissolution Test	2.5	
TES-006	Powder Flow Test	2.6	
TES-007	Stability Test	2.7	
TES-008	Slurry Test	2.8	
TES-009	Dry Powder Test	2.9	

Indicate the combined cost and the total number of hours that the test(s) will take. You do not need to consider the booking times for this/these test(s).

COST: $_______________

TOTAL TIME: _______________ minutes

Section 1 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
1	
2	
3	
4	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
1		
2		
3		
4		

Section 2

Estimated time: 20 minutes

At Corporation Inc., products require a wide range of additives during production. Suppliers compete to be the preferred supplier of Corporation Inc. Additive suppliers regularly offer free samples of their newest additives in the hope that Corporation Inc. will purchase more from them. The **Raw Materials Department** is responsible for the purchasing of all the additives. However the Raw Material Department relies on the expertise of the **Formulation Department** when deciding on which supplier to choose.

Your manager has received new samples from the **Raw Materials Department**. Your job is to evaluate the samples and report your findings. You will have to rank all the samples and then justify your ranking.

You are provided only with the information in the handouts. All the information you require in your evaluation is provided in the handouts. You should only use this information. Based on this information, your manager asks you to '**use your best judgement**'.

At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(5) Question 5

You will need:

- **Handouts #1.3 – 1.6 (MDS-001 – MDS-004)**
- **Handout #4.1 (MSS-001)**

The Material Specification Sheet (MSS-001) outlines the minimum requirements and whether each material property is preferred to be a high or low value. You should compare the values in the Material Data Sheets (MDS-001 – MDS-004) to the Specification Sheet and determine which sample is the most preferred.

Your manager has not told you which parts of the MDS are most important. You should consider the entire MDS.

Which sample is the most preferred? Rank the samples in order of preference.
[1 = MOST preferred; 4 = LEAST preferred]

Data Sheet Internal Code	Handout Number	Rank (1 – 4)
xLD-9134	1.3	
xLD-9135	1.4	
xLD-9136	1.5	
LD-5528	1.6	

(6) Question 6

You will need:

- **Handouts #1.3 – 1.6 (MDS-001 – MDS-004)**
- **Handout #4.1 (MSS-001)**

Your manager now wants you to justify your MOST preferred sample (ranked #1 in Question 5). Which data points were the most influential in deciding to CHOOSE that sample?

Using the headings from the MDS, indicate which data were most influential in your decision. Select the three (3) headings and rank your three (3) headings in order of importance.

For example, if your top three (3) reasons are "*Physical Form*", "*Melting Point*", and "*Density*" then you will write: 17, 11 and 27 on the lines below.

Heading (Rank #1): ___________ (write the number corresponding to the heading)

Heading (Rank #2): ___________

Heading (Rank #3): ___________

[1 = MOST influential reason you CHOSE that sample; 3 = LEAST influential]

Select only from the following Data Sheet headings:

	Document Header/Footer		Physical Properties
01	Document Version	17	Physical Form
02	Controller	18	Brightness (ISO) [%]
03	Authorising Person	19	Roughness [µm]
04	Version Date	20	Dust [mg/m^{-3}]
	Introduction	21	Scott Bonding [J/m^2]
05	Internal Code	22	Odour
06	Empirical Formula	23	Purity [%]
07	Supplier Product Name	24	Moisture [%]
08	Data Sheet Prep. Date	25	Conductivity [W/m.K]
	Chemical Properties	26	Viscosity (max. sol.) [Pa.s]
09	pH (max. sol.) [unit]	27	Density [g/dL]
10	Heat of Dissolution [kJ/kg]	28	Flammability in air [g/m^3]
11	Melting Point [°C]		Safety
12	Solubility in Water [kg/L]	29	PPE Req.
13	Partition K(C8|H) [unit]	30	Storage Label
14	Toxicity (STEL) [g/kg.hr]		Supplier History
15	Toxicity (LOEC) [g/kg.hr]	31	Supplier Company Name
16	Volatile Organics [%]	32	Cost [$/t]
		33	Supply History

(7) Question 7

You will need:

- **Handouts #1.3 – 1.6 (MDS-001 – MDS-004)**
- **Handout #4.1 (MSS-001)**

Your manager wants you to justify your LEAST preferred sample (ranked #4 in Question 5). Which data points were the most influential in deciding to NOT CHOOSE that sample?

Using the headings from the MDS, indicate which data were most influential in your decision. Select the three (3) headings and rank your three (3) headings in order of importance.

Heading (Rank #1): __________ (write the number corresponding to the heading)

Heading (Rank #2): __________

Heading (Rank #3): __________

[1 = MOST influential reason you did NOT CHOOSE that sample; 3 = LEAST influential]

Select only from the following Data Sheet headings:

Document Header/Footer

01 Document Version
02 Controller
03 Authorising Person
04 Version Date

Introduction

05 Internal Code
06 Empirical Formula
07 Supplier Product Name
08 Data Sheet Prep. Date

Chemical Properties

09 pH (max. sol.) [unit]
10 Heat of Dissolution [kJ/kg]
11 Melting Point [°C]
12 Solubility in Water [kg/L]
13 Partition K(C8|H) [unit]
14 Toxicity (STEL) [g/kg.hr]
15 Toxicity (LOEC) [g/kg.hr]
16 Volatile Organics [%]

Physical Properties

17 Physical Form
18 Brightness (ISO) [%]
19 Roughness [µm]
20 Dust [mg/m^{-3}]
21 Scott Bonding [J/m^2]
22 Odour
23 Purity [%]
24 Moisture [%]
25 Conductivity [W/m.K]
26 Viscosity (max. sol.) [Pa.s]
27 Density [g/dL]
28 Flammability in air [g/m^3]

Safety

29 PPE Req.
30 Storage Label

Supplier History

31 Supplier Company Name
32 Cost [$/t]
33 Supply History

Section 2 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
5	
6	
7	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
5		
6		
7		

Section 3

Estimated time: 20 minutes

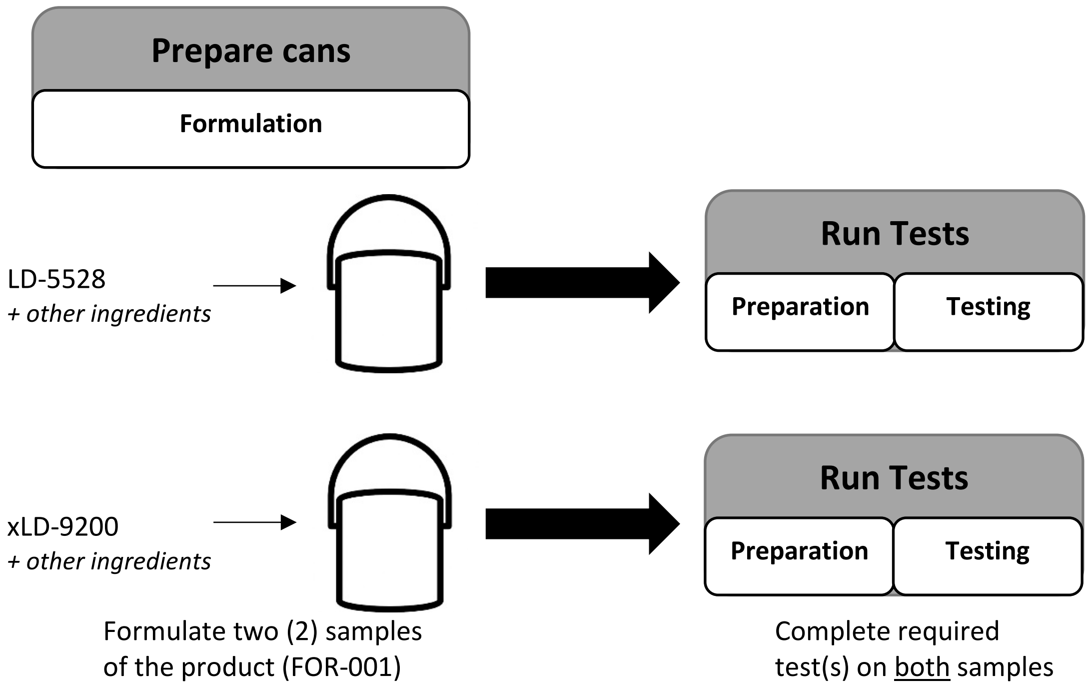
Congratulations on all your hard work in choosing the best sample for Corporation Inc. to use. Unfortunately another Corporation Inc. production site has provided a different additive to replace the old LD-5528 you have been working with. They say that this new additive (xLD-9200) will revolutionise the manufacturing process.

Your manager wants you to investigate whether xLD-9200 can be formulated into in Corporation Inc.'s products without ruining the products. You will be working with Corporation Inc.'s famous leading-brand canned product (code name: FOR-001).

You will need to prepare two cans of FOR-001 to test;

- one containing the current additive (LD-5528) with other ingredients, and
- one containing the replacement additive (xLD-9200) with other ingredients.

Your job is to prepare these two cans, test them separately, and report your findings.



At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(8) Question 8

You will need:

- **Handout #1.7 (MDS-772)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**

Before preparing the cans, your manager explains what data you need to find. You are provided with a material data sheet (MDS-772) showing you which data you will need to collect. The missing data is indicated on MDS-772 as greyed-out cells.

From experience, you know it is important to plan which tests you will need to do.

You want to collect the data using the least number of tests. Which test(s) should you undertake? Tick the box corresponding with each test(s) you would undertake.

Test	Test Name	Handout Number	Tick Box
TES-001	pH Test	2.1	
TES-002	Solubility Test	2.2	
TES-003	Drying Test	2.3	
TES-004	Optical Test	2.4	
TES-005	Dissolution Test	2.5	
TES-006	Powder Flow Test	2.6	
TES-007	Stability Test	2.7	
TES-008	Slurry Test	2.8	
TES-009	Dry Powder Test	2.9	

Number of tests you would do: _______________

(9) Question 9

You will need:

- **Handout #1.7 (MDS-772)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**

Before you can even start the testing, you have been told TES-005 is not available.

You will need to double-check your planned test(s). Will you need to change the test(s) that you want to do?

You want to collect the data using the least number of tests. Which test(s) should you undertake? Tick the box corresponding with each test(s) you would undertake.

Test	Test Name	Handout Number	Tick Box
TES-001	pH Test	2.1	
TES-002	Solubility Test	2.2	
TES-003	Drying Test	2.3	
TES-004	Optical Test	2.4	
TES-005	Dissolution Test	2.5	*Not available*
TES-006	Powder Flow Test	2.6	
TES-007	Stability Test	2.7	
TES-008	Slurry Test	2.8	
TES-009	Dry Powder Test	2.9	

Number of tests you would do: _______________

(10) Question 10

You will need:

- **Handouts #2.6 – 2.8 (TES-006 – TES-008)**
- **Handout #5.1 (FOR-001)**

Your manager wants to know how much it would cost to prepare and test both cans.

Determine the costs associated with FOR-001 (preparing the cans), and TES-006 – TES-008 (testing the cans).

It is important to minimise costs where possible.

(A) COSTS FROM FOR-001:

PREPARATION STEP: $______________

COMBINING STEP: $______________

(B) COSTS FROM TES-006 – TES-008:

	TES-006	TES-007	TES-008
PREPARATION PHASE:	$______________	$______________	$______________
TESTING PHASE:	$______________	$______________	$______________

ADD ALL YOUR COSTS TOGETHER:

TOTAL COST; (A) + (B): $______________

(11) Question 11

You will need:

- **Handout #2.8 (TES-008)**
- **Handout #3.1 (BOO-001)**
- **Handout #5.1 (FOR-001)**

Your manager has arranged for your colleague to complete TES-006, and TES-007 on the two products you formulated. You no longer need to do these tests.

Now your manager would like you to prepare the two products again and complete only TES-008.

Starting at 9 AM on Wednesday morning, what is the earliest day and time on which you can: (i) prepare these two cans, and then (ii) complete TES-008?

Remember you will be performing TES-008 on the two cans you prepare.

(i) Preparation of these two cans (FOR-001):

YOU WOULD FINISH ON (DAY): _______________

YOU WOULD FINISH AT (TIME): _______________

(ii) Followed by completion of test on the two cans (TES-008):

YOU WOULD FINISH ON (DAY): _______________

YOU WOULD FINISH AT (TIME): _______________

Section 3 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
8	
9	
10	
11	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
8		
9		
10		
11		

Section 4

Estimated time: 20 minutes

Your job now moves to the **Quality Control Department**. This department is responsible for ensuring the products being produced are of a high quality. To achieve this, the Quality Control Department is responsible for confirming all the materials in the factory are safe and appropriate. This often includes testing products to ensure they contain the right amounts of ingredients and do not contain any contaminations.

At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(12) Question 12

You will need:

- **Handout #5.1 (FOR-001)**
- **Handout #6.1 (BAT-001)**

Your manager requires you to double-check a batch production sheet. This batch production sheet (BAT-001) gives the key details the different batches of products produced on a specific day.

You are required to review all batches of FOR-001 that were being produced after 2:30 AM. Your manager only wants to know if the correct amounts of ingredients were added.

Which batch(es), if any, does/do not have the correct amounts of ingredients added? Place a cross (X) in line with each batch, if any, that does not have the correct amount of ingredients.

Batch 1		Batch 8		Batch 15	
Batch 2		Batch 9		Batch 16	
Batch 3		Batch 10		Batch 17	
Batch 4		Batch 11		Batch 18	
Batch 5		Batch 12		Batch 19	
Batch 6		Batch 13		Batch 20	
Batch 7		Batch 14			

Section 4 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
12	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
12		

Section 5

Estimated time: 15 minutes

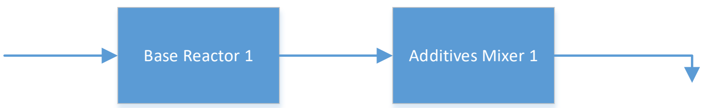
Your manager has identified a serious contamination in the products leaving the "Product Release Warehouse" factory.

The contamination must be coming from one or more of the processes shown in PFD-001.

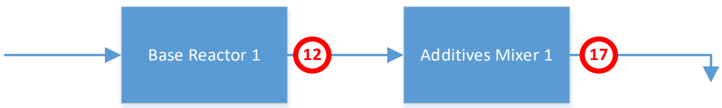
It is very important you find the cause of the contamination quickly.

You will be working with a specific type of technical diagram (PFD-001). Your manager explains to you how to read this type of diagram:

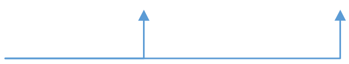
> "This diagram shows the different processes that occur in the factory. Every process is shown as a blue box with lines coming into it, and lines coming out of it. Here you can see one pipe entering the 'Base Reactor #1'. Next, material moves to 'Additives Mixer #1', and so on."



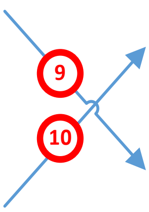
> "Most pipes have little sampling nozzles where you can safely extract some of the material for testing. These are called sample points and are numbered from 1 to 20. You can see sampling point 12 on the pipe AFTER 'Base Reactor #1' and sampling point 17 AFTER 'Additives Mixer #1'. The sample point numbers do not have any special meaning."



> "Sometimes pipes split into two separate pipes. Both of the split pipes carry the same material because they come from the same source. You can see what this looks like below."



> "Lastly, sometimes pipes need to go across each other without touching and without joining. This looks like a little jump on the pipes. Below you can see how the pipe with sample point 9 'jumps' over the other pipe with sample point 10. In the factory these pipes never touch."



At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(13) Question 13

You will need:

- **Handout #7.1 (PFD-001)**

Initial testing indicates there is no contamination in any of the ingredients entering the "Ingredient Import Warehouse". You are tasked with finding the cause of this contamination.

A quality control team has undertaken some preliminary work by testing some of the sample points. Using their results below, indicate which sample points are definitely contaminated and which sample points are definitely NOT contaminated.

Results:

- The contamination is not coming from any of the pipes
- Sample Point (S.P.) 5; NO contamination present
- S.P. 12; Contamination present
- S.P. 13; Contamination present

Note: When reading PFD-001, you should assume that pipes entering a process, or pipes exiting a process will be carrying equal quantities of product.

[Place a tick (√) next to all sample points (S.P.) that are DEFINITELY NOT contaminated.]
[Place a cross (X) next to all sample points (S.P.) that are DEFINITELY contaminated.]

S.P. 1		S.P. 8		S.P. 15	
S.P. 2		S.P. 9		S.P. 16	
S.P. 3		S.P. 10		S.P. 17	
S.P. 4		S.P. 11		S.P. 18	
S.P. 5		S.P. 12		S.P. 19	
S.P. 6		S.P. 13		S.P. 20	
S.P. 7		S.P. 14			

(14) Question 14

You will need:

- **Handout #7.1 (PFD-001)**

The lab results from the preliminary testing arrive. With these results, what is your next action?

The results are:

- S.P. 12; Contaminant = 100 ppm
- S.P. 13; Contaminant = 150 ppm

[Fill in the blank using words from the word list provided. The number in each blank refers to the column you can select words from. Place the number corresponding to your answer on the lines provided below.]

With this new information, your next action is to ______(1)_____ ______(2)_____.

Column (1) = ___________

Column (2) = ___________

[Select one number from Column (1) and select one number from Column (2)]

Column (1)		Column (2)			
1	test a sample from …	1	S.P. 1	11	S.P. 11
		2	S.P. 2	12	S.P. 12
		3	S.P. 3	13	S.P. 13
		4	S.P. 4	14	S.P. 14
		5	S.P. 5	15	S.P. 15
		6	S.P. 6	16	S.P. 16
		7	S.P. 7	17	S.P. 17
		8	S.P. 8	18	S.P. 18
		9	S.P. 9	19	S.P. 19
		10	S.P. 10	20	S.P. 20

- OR -

2	inform your manager that the source of the contamination is most likely in …	1	Additives Mixer 1	7	Combining Mixer
		2	Additives Mixer 2	8	Ingredient Import Warehouse (IN)
		3	Base Mixer 1	9	Mixing (Water)
		4	Base Mixer 2	10	Packaging
		5	Base Reactor 1	11	Powders Mill
		6	Base Reactor 2	12	Product Release Warehouse (OUT)

Section 5 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
13	
14	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
13		
14		

Section 6

Estimated time: 20 minutes

The following week, your manager asks you to investigate a problem they are experiencing in the factory. You are asked to determine the potential causes of this problem and the effects that this problem will have if it is left untreated.

The Problem:
"The problem is that we have to throw out an entire batch of product from the start of this week! Our client was expecting to receive this batch tomorrow and we don't have time to remake it!"

An Explanation:
"When the product comes back from testing, the scent has disappeared and the product has a putrid smell. I know that the scent has no effect on the performance of the product, but if we don't have a scent in the product then it is going to stink!"
"This has never happened before. I know for sure that everything in the 'Packaging and Product Release Warehouse (OUT)' is working perfectly. I think that everything else in the factory is working properly, but I can't be completely confident."

At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(15) Question 15

You will need:
- **Handout #5.1 (FOR-001)**
- **Handout #7.1 (PFD-001)**

What is causing the problem?

Classify these potential causes as being **plausible** or **implausible**, in this situation.
A **plausible cause** explains logically why the problem occurred, based only on the information provided.

Note that you only need to put each cause in the appropriate box. The rank of each cause within the boxes is not relevant.

POTENTIAL CAUSES
1. Contaminants generating unpleasant odour
2. Contaminants in process inhibiting S-1136 activity
3. Contaminated batch of S-1136 used
4. Insufficient JT-7735 used
5. Insufficient water added
6. Mechanical fault in the Additive Mixer
7. No S-1136 added
8. Packaging fault leading to UV degradation

(16) Question 16

You will need:
- **Handout #5.1 (FOR-001)**
- **Handout #7.1 (PFD-001)**

How might we solve the problem?

Your colleague asks you to suggest some potential solutions to **the problem**.

Classify these potential solutions as being **viable** or **inviable**, in this situation.
A **viable solution** could feasibly address the problem.

Note that you only need to put each solution in the appropriate box. The rank of each cause within the boxes is not relevant.

POTENTIAL SOLUTIONS
1. Add more S-1136 to the product and supply to the customer
2. Check all equipment for contamination and faults, and fix those
3. Contract another company to make the product to provide to the client
4. Explain to the client that the batch is actually not faulty, and there is only a problem with the scent
5. Find another client who would not have an issue with the scent
6. Review the procedures around cleaning and testing to identify any issues
7. Review the S-1136 batch for quality and contamination to prevent future problems
8. Supply the batch to the client anyway, without any changes
9. Upgrade the production facility to be fully automated, removing human error
10. Work overtime and get a new batch finished to give to the client

Section 6 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
15	
16	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
15		
16		

Section 7

Estimated time: 45 minutes

Your manager asks you to review a colleague's work. Your colleague has been testing new experimental samples from new suppliers:

- MDS-005 is a control sample that Corporation Inc. has tested many times previously, and it should be within specifications,
- MDS-006 – MDS-008 are the new experimental samples.

Your colleague requested a set of tests and has received the results in an email (RES-001). These results were then transferred on to MDS-005 – MDS-008.

You will need to review this work and identify if any errors exist. Errors may come from human mistakes or from machinery faults. If errors exist you shall determine where they may have come from.

Please note:

- It is important to evaluate all the results together.
- All results should be compared to the standard sample.
- A sample that is not within specification may or may not be an error.

You should ignore any blank entries in MDS-005 – MDS-008; these data points have not been collected and are not important.

At the end of this section you will be asked:

- **to estimate how long each question took to complete, and**
- **whether you made any notes to help solve the questions.**

(17) Question 17

You will need:

- **Handouts #1.8 – 1.11 (MDS-005 – MDS-008)**
- **Handout #2.3 & #2.9 (TES-003 & TES-009)**
- **Handout #4.1 (MSS-001)**
- **Handout #8.1 (RES-001)**

Fill in the grid below to indicate whether the results have no errors (“tick”) or whether there are errors (“cross”).

You should ignore any blank entries in MDS-005 – MDS-008.

[You should mark every box with either a TICK (√) or a CROSS (X)]

	MDS-005	MDS-006	MDS-007	MDS-008
	Standard	*Exp.X1*	*Exp.X2*	*Exp.X3*
Melting Pt. [°C]				
Toxicity (STEL) [g/kg.hr]				
Toxicity (LOEC) [g/kg.hr]				
Roughness [µm]				
Dust [mg/m^{-3}]				
Scott Bonding [J/m^2]				
Moisture [%]				
Conductivity [W/m.K]				
Density [g/dL]				
Flammability in air [g/m^3]				

(18) Question 18

You will need:

- **Handouts #1.8 – 1.11 (MDS-005 – MDS-008)**
- **Handout #2.3, #2.9 (TES-003, TES-009)**
- **Handout #8.1 (RES-001)**

Errors can be caused by human mistakes or machinery faults.

For every CROSS in Question 17, now indicate whether these errors could be caused by human (“H”), or machinery (“M”), or either of human or machinery (“E”).

[You should put one of “H”, “M”, or “E” only in the boxes you CROSSED in the previous question. Other boxes should be left blank.]

	MDS-005	MDS-006	MDS-007	MDS-008
	Standard	*Exp.X1*	*Exp.X2*	*Exp.X3*
Melting Pt. [°C]				
Toxicity (STEL) [g/kg.hr]				
Toxicity (LOEC) [g/kg.hr]				
Roughness [µm]				
Dust [mg/m^{-3}]				
Scott Bonding [J/m^2]				
Moisture [%]				
Conductivity [W/m.K]				
Density [g/dL]				
Flammability in air [g/m^3]				

Section 7 Summary

(1) Please indicate how long each question took to complete.

Question	Time Taken (min)
17	
18	

(2) Please indicate whether you made any notes to help in solving the question.

Question	Handwritten	Electronic
17		
18		

10.11 Appendix 11. Chapter 6: Monash businessThink (version 7) auxiliary documents

businessThink
Measuring Industry Critical Abilities

SECTION 1

- **Handout#1.1 (MDS-00x)**
- **Handout #1.2 (MDS-00y)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**
- **Handout #3.1 (BOO-001)**

MDS-00x (xLD-9000)		HANDOUT #1.1		Ci
Doc. Version:	1.0		Controller:	Raw Ingred.

IDENTIFICATION			
▪ Internal Code	xLD-9000	▪ Supplier Product Name	Silicea
▪ Empirical Formula	SiO_2/SiO_4	▪ Data Sheet Prep. Date	01/01/2018
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	6.55 ± 0.02	▪ Partition K(C_8|H) [unit]	17
▪ Heat of Dissol. [kJ/kg]	0.335 ± 0.001	▪ Toxicity (STEL) [g/kg.hr]	
▪ Melting Pt. [ºC]	1820	▪ Toxicity (LOEC) [g/kg.hr]	
▪ Solubility in Water [kg/L]		▪ Volatile Organics [%]	< 0.1
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	
▪ Brightness (ISO) [%]	97.5	▪ Moisture [%]	5.00
▪ Roughness [µm]	100	▪ Conductivity [W/m.K]	0.003
▪ Dust [mg/m^3]		▪ Viscosity (max. sol.) [Pa.s]	
▪ Scott Bonding [J/m^2]	6.393	▪ Density [g/dL]	
▪ Odour		▪ Flammability in air [g/m^3]	N/A
SAFETY			
▪ PPE Req.	Respirator, safety goggles, gloves	▪ Storage Label	N/A
SUPPLIER INFORMATION			
▪ Supplier Company Name	Powders R' Us	▪ Cost [$/t]	900.0
▪ Supply History			
New supplier			

Authorised: JW Version Date: 28/02/2018

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MDS-00y (xLD-9525)	HANDOUT #1.2			Ci
Doc. Version:	1.0		Controller:	Raw Ingred.

IDENTIFICATION			
▪ Internal Code	xLD-9525	▪ Supplier Product Name	Insilicate
▪ Empirical Formula	SiO2/SiO4	▪ Data Sheet Prep. Date	01/01/2017
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	6.38 ± 0.02	▪ Partition K(C_8|H) [unit]	16
▪ Heat of Dissol. [kJ/kg]		▪ Toxicity (STEL) [g/kg.hr]	1.22E-08
▪ Melting Pt. [ºC]		▪ Toxicity (LOEC) [g/kg.hr]	5.00E-11
▪ Solubility in Water [kg/L]		▪ Volatile Organics [%]	< 0.1
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	96.38 ± 0.01
▪ Brightness (ISO) [%]	91	▪ Moisture [%]	
▪ Roughness [μm]	110	▪ Conductivity [W/m.K]	
▪ Dust [mg/m³]		▪ Viscosity (max. sol.) [Pa.s]	0.982
▪ Scott Bonding [J/m²]	6.423	▪ Density [g/dL]	
▪ Odour	NONE	▪ Flammability in air [g/m³]	N/A
SAFETY			
▪ PPE Req.	Respirator, safety goggles, gloves	▪ Storage Label	N/A
SUPPLIER INFORMATION			
▪ Supplier Company Name	Powders R' Us	▪ Cost [$/t]	905.0
▪ Supply History			
New supplier			

Authorised: JW

Version Date: 28/02/2017

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TES-001 (pH Test)		HANDOUT #2.1		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **pH TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- pH / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**pH TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 15 min	pH Meters: 15 min

3.2 This test requires: 50 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**pH TEST**)
  - Materials cost: $ 1 per gram
  - Equipment cost: $ 50

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

Authorised: PG Version Date: 15/08/2012

TES-001 (pH Test)	HANDOUT #2.1		Ci	
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

5.1 None

[TESTING PHASE]

15 min (Benches)

5.2 Weigh out 50.0 grams of the sample, precisely.

For LIQUID, go to Step 5.4.
For POWDER/SLURRY/EMULSION, go to Step 5.3.

5.3 **FOR POWDER/SLURRY/EMULSION ONLY**
Dissolve/disperse this sample into 50.0 grams of deionised water. Stir thoroughly to dissolve/disperse sample.

15 min (pH Meters)

5.4 Rinse any available pH meter probe with deionised water.

5.5 Place probe in sample solution and press the [MEASURE] button.

5.6 Reading will stabilise within 15 seconds. When reading stabilises, read pH value from the display.

5.7 Rinse probe and return probe to storage solution.

TES-002 (Solubility Test)		HANDOUT #2.2		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **SOLUBILITY TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Solubility in Water [kg/L] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**SOLUBILITY TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 10 min	Mixers: 20 min

3.2 This test requires: 100 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**SOLUBILITY TEST**)
  - Materials cost: $ 5 per gram
  - Equipment cost: $ 150

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

TES-002 (Solubility Test)	HANDOUT #2.2			Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

5.1 None

[TESTING PHASE]

10 min (Benches)

5.2 Weigh out 100.0 grams of sample, precisely.

5.3 Allow sample to cool to room temperature.

5.4 Measure 100.0 mL of deionised water, at 20ºC.

5.5 Place water on laboratory scale with mixer and note the initial weight.

20 min (Mixers)

5.6 Using any available mixer, add dried sample slowly to the water, mixing continuously. This process will take 10 minutes of constant addition.

5.7 Continue sample addition until a visible solid can be seen at the top or bottom of the water. This solution should be mixed for 5 minutes to ensure that no more dissolution occurs.

5.8 Note the final weight (grams) and calculate the solubility as:

$$\frac{(m_f - m_i)}{100.0}$$

TES-003 (Drying Test)		HANDOUT #2.3		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DRYING TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Melting Point [ºC] / 0.0 / ± 0.1
- Purity [%] / 0.00 / ± 0.01
- Moisture [%] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**DRYING TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 15 min	Ovens: 45 min

3.2 This test requires: 100 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**DRYING TEST**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 100

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

Authorised: PG Version Date: 15/08/2012

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TES-003 (Drying Test)		HANDOUT #2.3		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

5.1 None

[TESTING PHASE]

15 min (Benches)

5.2 Weigh out 50.0 grams of the sample, precisely.

5.3 Place sample on to foil tray and spread evenly.

5.4 Weigh tray with sample and record initial weight.

45 min (Ovens)

5.5 Place tray in any available oven at 120ºC for 15 minutes.

5.6 While drying is occurring, clean preparation area thoroughly.

5.7 Remove tray and let sample return to room temperature.

5.8 Weigh dried sample with tray and record final weight. Calculate the moisture content as:

$$\frac{(m_f - m_i)}{100}$$

5.9 Repeat steps 5.2 and 5.3.

5.10 Calibrate the melting point apparatus before each test to ensure accurate readings.

5.11 Place tray in controlled oven, starting at 100ºC with heat gradient set at 2ºC/min. Press [START] to begin melting point test.

5.12 After 25 minutes, read melting point reading from front display.

5.13 While melting is occurring, clean area thoroughly and prepare for removal of sample(s).

5.14 Remove foil tray and dispose.

TES-004 (Optical Test)		**HANDOUT #2.4**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **OPTICAL TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Brightness (ISO) [%] / 0 / ± 2
- Roughness [µm] / 0 / ± 10
- Dust [mg/m³] / 0.00 / ± 0.05

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRYING**)		Testing (**OPTICAL TEST**)	
Benches: 15 min	Ovens: 45 min	Benches: 0 min	Microscope: 30 min

3.2 This test requires: 50 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRYING**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200

- Testing (**OPTICAL TEST**)
  - Materials cost: $ 10 per gram
  - Equipment cost: $ 150

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- Microscope. Equipment must booked.

Authorised: PG

Version Date: 15/08/2012

TES-004 (Optical Test)	HANDOUT #2.4			Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
15 min (Benches)	5.1	Weigh out 50.0 grams of the sample, precisely.
	5.2	Place sample on to foil tray and spread evenly.
45 min (Ovens)	5.3	Wait for preheating. Spread sample thinly on plate & prepare documentation.
	5.4	Insert tray in any available oven.
	5.5	*Must wait for 30 minutes.*
		You may pause the process here
		[TESTING PHASE]
30 min (Microscope)	5.6	Clean microscope light emitter.
	5.7	Open rear sample hatch.
	5.8	Insert microscopy tubule.
	5.9	On the front panel, set-up Brightness, Roughness and Dust Testing schema. This can be selected using the keypad with the following keystrokes; [UP], [UP], [DOWN], [DOWN], [LEFT], [RIGHT], [LEFT], [RIGHT], [A], [B].
	5.10	Press [START].
	5.11	*Must wait for 30 minutes.*
0 min (Microsc.)	5.12	Read results from front panel.
	5.13	Remove microscopy tubule from rear hatch.
	5.14	Clean microscope light emitter.

TES-005 (Dissolution Test)		HANDOUT #2.5		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DISSOLUTION TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- pH / 0.00 / ± 0.01
- Heat of Dissolution [kJ/kg] / 0.00 / ± 0.01
- Solubility in Water [kg/L] / 0.00 / ± 0.01
- Partition K(C_8|H) / 0 / ± 0.5
- Odour
- Conductivity / 0.000 / ± 0.001
- Viscosity (max. sol.) [Pa.s] / 0.000 / ± 0.001

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**SHEAR MIXING**)		Testing (**DISSOLUTION TEST**)	
Benches: 0 min	High Shear Mixer: 30 min	Benches: 30 min	Mixers: 30 min

3.2 This test requires: 100 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**SHEAR MIXING**)
    - Materials cost: $ 3.5 per gram
    - Equipment cost: $ 300

- Testing (**DISSOLUTION TEST**)
    - Materials cost: $ 5 per gram
    - Equipment cost: $ 150

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- High Shear Mixer. Equipment must be booked.

Authorised: PG Version Date: 15/08/2012

TES-005 (Dissolution Test)	**HANDOUT #2.5**			
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

30 min (H. Shear Mixer)

5.1 Weigh out 100.0 grams of the sample, precisely.

5.2 Ensure that high shear mixer bowl is clean and free from contamination and moisture.

5.3 Add sample to high shear mixer bowl.

5.4 Set to highest shear setting and press [START].

5.5 *Must wait for 30 minutes.*

You may pause the process here

[TESTING PHASE]

30 min (Benches)

5.6 Take 25.0 grams of the sheared sample and place it in a crucible mixer.

5.7 Set up a drip-pipe with a water header at an addition rate of 2 mL/min.

5.8 Open drip-pipe outlet until all of the sample is dissolved.

5.9 Read the heat of dissolution from the front meter on the crucible mixer.

5.10 Carefully sniff the product and note any detectable odour.

5.11 Attach the pH probe to any avilable crucible mixer.

5.12 Place probe in the sample and read result from the front panel on the crucible mixer.

You may pause the process here

30 min (Mixers)

5.13 Repeat steps 5.10 and 5.11 for the Solubility probe.

5.14 Repeat steps 5.10 and 5.11 for the Conductivity probe.

5.15 Repeat steps 5.10 and 5.11 for the Viscosity probe.

5.16 Dispose of sample.

5.17 Repeat steps 5.6 – 5.10 using a 25%/75% octanol/water solution.

5.18 Attach Partition probe to the crucible mixer.

5.19 Place probe in sample and read result from the front panel on the crucible mixer.

5.20 Dispose of sample.

TES-006 (Powder Flow Test)		HANDOUT #2.6		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **POWDER FLOW TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Dust [mg/m³] / 0.000 / ± 0.001
- Scott Bonding [J/m²] / 0.000 / ± 0.001
- Flammability in Air [g/m³] / 0 / ± 10
- PPE Requirement

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**SIEVING**)		Testing (**POWDER FLOW TEST**)	
Benches: 0 min	Sieve Rack: 60 min	Benches: 0 min	Free-Flow Tester: 60 min

3.2 This test requires: 100 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**SIEVING**)
  - Materials cost: $ 7 per gram
  - Equipment cost: $ 400

- Testing (**POWDER FLOW TEST**)
  - Materials cost: $ 1 per gram
  - Equipment cost: $ 50

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- Sieve Rack. Equipment must be booked.
- Free-Flow Tester. Equipment must be booked.

Authorised: PG Version Date: 15/08/2012

TES-006 (Powder Flow Test)	HANDOUT #2.6		Ci	
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

60 min (Sieve Rack)

5.1 Open sieving apparatus.

5.2 Ensure that sieve meshes are clear from debris or residue.

5.3 Insert calibration powder into top sieve mesh. Close apparatus.

5.4 Run sieve rack by pressing [CALIBRATE].

5.5 At end of calibration, ensure that all powder has fallen through the bottom sieve.

5.6 Remove remaining powder and clear meshes.

5.7 Weigh out 100.0 grams of sample, precisely.

5.8 Insert sample into top sieve mesh.

5.9 Run sieve rack at 60 rpm.

5.10 *Must wait for 30 minutes.*

You may pause the process here

0 min (Free-Flow Tester)

5.11 Collect powder from bottom sieve.

[TESTING PHASE]

5.12 Fill free-flow tester sample tube with approximately 10 grams of powder, ensuring that no air bubbles are present.

Please note that the exact mass of powder does not need to be recorded and has no effect on the results of the free-flow powder testing.

60 min (Free-Flow Tester)

5.13 Introduce the sample tube to the free-flow powder tester.

5.14 On the front panel, select [DUSTING], [BONDING] and [FLAME]. Then press [START].

5.15 After approximately 10 minutes, record the results from the front panel.

5.16 Remove and discard sample tube.

5.17 Repeat steps 5.12 – 5.16 until all of the sieved sample has been consumed.

5.18 Find the mean average results of each test and record these as the final figures.

5.19 For any dust result greater than 0.01 mg/m³, record the PPE requirement as "Gloves, Dust Mask"

TES-007 (Stability Test)		HANDOUT #2.7		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **STABILITY TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Toxicity (STEL) [g/kg.hr] / 0.00E-09 / ± 0.01E-09
- Toxicity (LOEC) [g/kg.hr] / 0.00E-11 / ± 0.01E-11
- Volatile Organics [%] / 0.0 / ± 0.1
- Odour
- Density [g/dL] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**SHEAR MIXING**)		Testing (**STABILITY TEST**)	
Benches: 0 min	High Shear Mixer: 30 min	Benches: 0 min	Advanced Stabiliser: 60 min

3.2 This test requires: 150 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**SHEAR MIXING**)
  - Materials cost: $ 3.5 per gram
  - Equipment cost: $ 300

- Testing (**STABILITY TEST**)
  - Materials cost: $ 10 per gram
  - Equipment cost: $ 450

4. REQUIRED EQUIPMENT

4.1 This test requires the following specialised equipment:

- High Shear Mixer. Equipment must booked.
- Advanced Stabiliser. Equipment must booked.

Authorised: PG Version Date: 15/08/2012

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TES-007 (Stability Test)		**HANDOUT #2.7**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
30 min (H. Shear Mixer)	5.1	Weigh out 150.0 grams of the sample, precisely.
	5.2	Ensure that high shear mixer bowl is clean and free from contamination and moisture.
	5.3	Add sample to high shear mixer bowl.
	5.4	Set to highest shear setting and press [START].
	5.5	*Must wait for 30 minutes.*
		You may pause the process here
		[TESTING PHASE]
60 min (Adv. Stabiliser)	5.6	Separate sample into equal 50.0 gram amounts.
	5.7	Place each 50.0 gram sample into a 100 mL conical flask.
	5.8	Add 25.0 mL of deionised water into two conical flasks.
	5.9	Stir to dissolve sample.
	5.10	Carefully sniff the dissolved samples and note any detectable odour.
	5.11	Cover the two flasks containing the dissolved samples with Protex film to stop air transfer into the flask.
	5.12	Place all flasks in the advanced stabiliser
	5.13	In the uncovered flask (non-dissolved sample), place the sampling probe.
	5.14	Close the top flap and start the machine pump and heater.
	5.15	*Must wait for 30 minutes.*
0 min (Adv. Stab.)	5.16	Record the STEL and LOEC measurements from the front panel, and the density from the secondary panel.
	5.17	Carefully observe the two covered samples for any discolouration.
	5.18	Dispose of all samples.

Authorised: PG Version Date: 15/08/2012

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TES-008 (Slurry Test)		HANDOUT #2.8		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **SLURRY TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Empirical Formula
- Heat of Dissolution [kJ/kg] / 0.00 / ± 0.01
- Odour
- Purity [%] / 0.00 / ± 0.01
- Viscosity (max. sol.) [Pa.s] / 0.000 / ± 0.001

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRY** & **SHEAR MIXING**)			Testing (**SLURRY TEST**)	
Benches: 15 min	Ovens: 45 min	High Shear Mixer: 30 min	Benches: 30 min	Restrict-Flow Tester: 150 min

3.2 This test requires: 200 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRY**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200
- Preparation (**SHEAR MIXING**)
  - Materials cost: $ 3.5 per gram
  - Equipment cost: $ 300
- Testing (**SLURRY TEST**)
  - Materials cost: $ 8 per gram
  - Equipment cost: $ 600

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- High Shear Mixer. Equipment must be booked.
- Restrict-Flow Tester. Equipment must be booked.

TES-008 (Slurry Test)		**HANDOUT #2.8**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

15 min (Benches)	5.1	Weigh out 200.0 grams of the sample, precisely.
	5.2	Place sample on to two foil trays and spread evenly.
45 min (Ovens)	5.3	Preheat any available oven to 180ºC.
	5.4	Place tray in oven.
	5.5	*Must wait for 30 minutes.*
		You may pause the process here
30 min (H. Shear Mixer)	5.6	Remove tray and let sample return to room temperature.
	5.7	Add sample to high shear mixer bowl.
	5.8	Set to highest shear setting and press [START]
	5.9	*Must wait for 30 minutes.*
		You may pause the process here

[TESTING PHASE]

30 min (Benches)	5.10	Transfer sheared sample to 2L glass container.
	5.11	Slowly add deionised water while constantly stirring until no more dry powder can be seen.
		You may pause the process here
150 min (R. Flow Tester)	5.12	Carefully transfer all of this into the top hopper of the restrict-flow meter.
	5.13	Select "Testing Parameters: 2" using the front keypad.
	5.14	Press [START].
	5.15	*Must wait for 120 minutes.*
0 min (R. Flow)	5.16	Note down all results from the front panel.
	5.17	Shutdown machine.

Authorised: PG Version Date: 15/08/2012

TES-009 (Dry Powder Test)		HANDOUT #2.9		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DRY POWDER TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY

1.3 Refer to the appropriate MDS to find the material's Physical Form.

1.4 The FLOW DETECTOR undertakes eight (8) separate tests, using eight (8) separate detectors. Results for each test should be considered independently.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Toxicity (STEL) [g/kg.hr] / 0.00E-09 / ± 0.01E-09
- Toxicity (LOEC) [g/kg.hr] / 0.00E-11 / ± 0.01E-11
- Brightness (ISO) [%] / 0 / ± 1
- Roughness [μm] / 0 / ± 5
- Dust [mg/m³] / 0.00 / ± 0.05
- Scott Bonding [J/m²] / 0.000 / ± 0.001
- Moisture [%] / 0.00 / ± 0.01
- Density [g/dL] / 0.00 / ± 0.01
- Flammability in Air [g/m³] / 0 / ± 10
- PPE Requirement

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRY** & **SIEVE**)			Testing (**DRY POWDER TEST**)	
Benches: 15 min	Ovens: 45 min	Sieve Rack: 60 min	Benches: 30 min	Flow Detector: 240 min

3.2 This test requires: 50 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRY**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200
- Preparation (**SIEVE**)
  - Materials cost: $ 7 per gram
  - Equipment cost: $ 400
- Testing (**DRY POWDER TEST**)
  - Materials cost: $ 35 per gram
  - Equipment cost: $ 750

4. REQUIRED EQUIPMENT

4.1 This test requires the following specialised equipment:

- Sieve Rack. Equipment must be booked.
- Flow Detector. Equipment must be booked.

TES-009 (Dry Powder Test)		**HANDOUT #2.9**		
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

15 min (Benches)

5.1 Weigh out 50.0 grams of the sample, precisely.

5.2 Place sample on to two foil trays and spread evenly.

45 min (Ovens)

5.3 Preheat any available oven to 180ºC. Then place tray in oven.

5.4 *Must wait for 30 minutes.*

You may pause the process here

60 min (Sieve Rack)

5.5 Ensure that sieve meshes are clear from debris or residue.

5.6 Insert calibration powder into top sieve mesh. Close apparatus.

5.7 Run sieve rack by pressing [CALIBRATE].

5.8 Check meshes and remove powder.

5.9 Weigh out 100.0 grams of sample, precisely and insert into top sieve mesh.

5.10 Run sieve rack at 60 rpm.

5.11 *Must wait for 30 minutes.*

You may pause the process here

[TESTING PHASE]

30 min (Benches)

5.12 Transfer sieved sample to 2L glass container.

5.13 Slowly add deionised water while constantly stirring until no more dry powder can be seen.

210 min (Flow Detector)

5.14 Carefully transfer all of this into the top hopper of the flow detector.

5.15 Press [START].

5.16 *Must wait for 180 minutes.*

You may pause the process here

30 min (Flow Detector)

5.17 Note down all results from the front panel.

5.18 For any dust result greater than 0.01 mg/m^3, record the PPE requirement as "Gloves, Dust Mask"

5.19 Clean-up and shutdown machine.

6. SAFETY NOTES

6.1 Please familiarise yourself with the following safety notes:

- Specialised equipment with multiple tests conducted [1]
- Ensure appropriate training [2]
- Equipment will always give the result of NO HALFLIFE [3]

1. The Flow Detector contains eight (8) separate testing apparatus. The results of each test should be considered separately.
2. Please ensure that you are appropriately inducted and authorised to use this equipment.
3. This equipment is not suitable for use with radioactive material.

BOO-001 (Booking Schedule)	HANDOUT #3.1		Ci
Doc. Version: 1.0		Controller:	Quality Control

Booking Schedule (VALID FOR THE NEXT 3 WEEKS)

Key:
- Busy
- Free

NOTE: Equipment can NOT be run overnight. All equipment will be emptied and cleaned at 5 PM each day.

Equipment	Booking Req.?	Mon 9-9.30	Mon 9.30-10	Mon 10-10.30	Mon 10.30-11	Mon 11-11.30	Mon 11.30-12	Mon 12-12.30	Mon 12.30-1	Mon 1-1.30	Mon 1.30-2	Mon 2-2.30	Mon 2.30-3	Mon 3-3.30	Mon 3.30-4	Mon 4-4.30	Mon 4.30-5
Adv. Stabiliser	YES																
Flow Detector	YES																
Free-flow Tester	YES																
High Shear Mixer	YES																
Microscope	YES																
Restrict-flow Tester	YES																
Sieve Rack	YES																

Equipment	Booking Req.?	Tue 9-9.30	Tue 9.30-10	Tue 10-10.30	Tue 10.30-11	Tue 11-11.30	Tue 11.30-12	Tue 12-12.30	Tue 12.30-1	Tue 1-1.30	Tue 1.30-2	Tue 2-2.30	Tue 2.30-3	Tue 3-3.30	Tue 3.30-4	Tue 4-4.30	Tue 4.30-5
Adv. Stabiliser	YES																
Flow Detector	YES																
Free-flow Tester	YES																
High Shear Mixer	YES																
Microscope	YES																
Restrict-flow Tester	YES																
Sieve Rack	YES																

Equipment	Booking Req.?	Wed 9-9.30	Wed 9.30-10	Wed 10-10.30	Wed 10.30-11	Wed 11-11.30	Wed 11.30-12	Wed 12-12.30	Wed 12.30-1	Wed 1-1.30	Wed 1.30-2	Wed 2-2.30	Wed 2.30-3	Wed 3-3.30	Wed 3.30-4	Wed 4-4.30	Wed 4.30-5
Adv. Stabiliser	YES																
Flow Detector	YES																
Free-flow Tester	YES																
High Shear Mixer	YES																
Microscope	YES																
Restrict-flow Tester	YES																
Sieve Rack	YES																

Authorised: JG   Version Date: 12/04/2017

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BOO-001 (Booking Schedule)	HANDOUT #3.1		Ci
Doc. Version: 1.0		Controller:	Quality Control

Equipment	Booking Req.?	Thu 9-9.30	Thu 9.30-10	Thu 10-10.30	Thu 10.30-11	Thu 11-11.30	Thu 11.30-12	Thu 12-12.30	Thu 12.30-1	Thu 1-1.30	Thu 1.30-2	Thu 2-2.30	Thu 2.30-3	Thu 3-3.30	Thu 3.30-4	Thu 4-4.30	Thu 4.30-5
Adv. Stabiliser	YES																
Flow Detector	YES																
Free-flow Tester	YES																
High Shear Mixer	YES																
Microscope	YES																
Restrict-flow Tester	YES																
Sieve Rack	YES																

Equipment	Booking Req.?	Fri 9-9.30	Fri 9.30-10	Fri 10-10.30	Fri 10.30-11	Fri 11-11.30	Fri 11.30-12	Fri 12-12.30	Fri 12.30-1	Fri 1-1.30	Fri 1.30-2	Fri 2-2.30	Fri 2.30-3	Fri 3-3.30	Fri 3.30-4	Fri 4-4.30	Fri 4.30-5
Adv. Stabiliser	YES																
Flow Detector	YES																
Free-flow Tester	YES																
High Shear Mixer	YES																
Microscope	YES																
Restrict-flow Tester	YES																
Sieve Rack	YES																

Blank Schedule (for planning)

	9-9.30	9.30-10	10-10.30	10.30-11	11-11.30	11.30-12	12-12.30	12.30-1	1-1.30	1.30-2	2-2.30	2.30-3	3-3.30	3.30-4	4-4.30	4.30-5
Monday																
Tuesday																
Wednesday																
Thursday																
Friday																
Monday																
Tuesday																
Wednesday																
Thursday																
Friday																
Monday																
Tuesday																
Wednesday																
Thursday																
Friday																

Authorised: JG   Version Date: 12/04/2017

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SECTION 2

- **Handouts #1.3 – 1.6 (MDS-001 – MDS-004)**
- **Handout #4.1 (MSS-001)**

MDS-001 (xLD-9134)	HANDOUT #1.3			
Doc. Version:	1.0		Controller:	Raw Ingred.

IDENTIFICATION			
▪ Internal Code	xLD-9134	▪ Supplier Product Name	Bright Silex
▪ Empirical Formula	SiO2/SiO4	▪ Data Sheet Prep. Date	01/01/2010
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	6.55 ± 0.02	▪ Partition K(C_8|H) [unit]	17
▪ Heat of Dissol. [kJ/kg]	0.335 ± 0.001	▪ Toxicity (STEL) [g/kg.hr]	1.20E-08
▪ Melting Pt. [ºC]	1771	▪ Toxicity (LOEC) [g/kg.hr]	3.94E-11
▪ Solubility in Water [kg/L]	< 1	▪ Volatile Organics [%]	< 0.1
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	94.00 ± 0.01
▪ Brightness (ISO) [%]	92	▪ Moisture [%]	4.60
▪ Roughness [µm]	100	▪ Conductivity [W/m.K]	0.003
▪ Dust [mg/m³]	0.13	▪ Viscosity (max. sol.) [Pa.s]	0.991
▪ Scott Bonding [J/m²]	6.393	▪ Density [g/dL]	208.42
▪ Odour	NONE	▪ Flammability in air [g/m³]	N/A
SAFETY			
▪ PPE Req.	Respirator, safety goggles, gloves	▪ Storage Label	N/A
SUPPLIER INFORMATION			
▪ Supplier Company Name	KDS Powders	▪ Cost [$/t]	885.0
▪ Supply History			
	New supplier		

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: JW Version Date: 30/09/2015

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MDS-002 (xLD-9135)		HANDOUT #1.4		Ci
Doc. Version:	1.0		Controller:	Raw Ingred.

IDENTIFICATION			
▪ Internal Code	xLD-9135	▪ Supplier Product Name	Silex
▪ Empirical Formula	$SiO2/SiO4$	▪ Data Sheet Prep. Date	28/09/2015
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	7.0 ± 0.1	▪ Partition $K(C_8 \mid H)$ [unit]	18
▪ Heat of Dissol. [kJ/kg]	0.301 ± 0.001	▪ Toxicity (STEL) [g/kg.hr]	6.79E-09
▪ Melting Pt. [ºC]	1800	▪ Toxicity (LOEC) [g/kg.hr]	2.05E-11
▪ Solubility in Water [kg/L]	< 1	▪ Volatile Organics [%]	< 5
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	96.76 ± 0.01
▪ Brightness (ISO) [%]	88	▪ Moisture [%]	3.9
▪ Roughness [µm]	125	▪ Conductivity [W/m.K]	0.004
▪ Dust [mg/m^3]	0.23	▪ Viscosity (max. sol.) [Pa.s]	0.991
▪ Scott Bonding [J/m^2]	6.190	▪ Density [g/dL]	213.01
▪ Odour	LOW	▪ Flammability in air [g/m^3]	1050
SAFETY			
▪ PPE Req.	Respirator, safety goggles, gloves	▪ Storage Label	N/A
SUPPLIER INFORMATION			
▪ Supplier Company Name	SilConstructions	▪ Cost [$/t]	880.5
▪ Supply History			
Supplies rival company (5+ yrs)			

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: JW

Version Date: 31/09/2015

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MDS-003 (xLD-9136)		HANDOUT #1.5		
Doc. Version:	1.0		Controller:	Raw Ingred.

IDENTIFICATION			
▪ Internal Code	xLD-9136	▪ Supplier Product Name	CrySil
▪ Empirical Formula	SiO2/SiO4	▪ Data Sheet Prep. Date	2/03/2015
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	7 ± 0.1	▪ Partition K(C8 | H) [unit]	19
▪ Heat of Dissol. [kJ/kg]	0.3 ± 0.01	▪ Toxicity (STEL) [g/kg.hr]	5E-09
▪ Melting Pt. [ºC]	1.8E+03	▪ Toxicity (LOEC) [g/kg.hr]	4E-11
▪ Solubility in Water [kg/L]	< 5	▪ Volatile Organics [%]	< 5
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	95 ± 0.2
▪ Brightness (ISO) [%]	96	▪ Moisture [%]	3.6
▪ Roughness [μm]	125	▪ Conductivity [W/m.K]	2E-3
▪ Dust [mg/m³]	3.0E-01	▪ Viscosity (max. sol.) [Pa.s]	0.99
▪ Scott Bonding [J/m²]	7.0	▪ Density [g/dL]	208.62
▪ Odour	NONE	▪ Flammability in air [g/m³]	900
SAFETY			
▪ PPE Req.	Respirator, safety goggles, gloves	▪ Storage Label	N/A
SUPPLIER INFORMATION			
▪ Supplier Company Name	Worster & Worster Society	▪ Cost [$/t]	887.5
▪ Supply History			
Supplies rival company (3+ yrs)			

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: JW Version Date: 31/09/2015

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MDS-004 (LD-5528)	HANDOUT #1.6			Ci
Doc. Version:	3.4		Controller:	Raw Ingred.

IDENTIFICATION			
▪ Internal Code	LD-5528	▪ Supplier Product Name	Compounding Silica
▪ Empirical Formula	SiO2/SiO4	▪ Data Sheet Prep. Date	30/06/2008
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	6.6 ± 0.3	▪ Partition K(C_8 | H) [unit]	18
▪ Heat of Dissol. [kJ/kg]	0.383 ± 0.001	▪ Toxicity (STEL) [g/kg.hr]	5.39E-09
▪ Melting Pt. [ºC]	1830	▪ Toxicity (LOEC) [g/kg.hr]	4.77E-11
▪ Solubility in Water [kg/L]	< 3	▪ Volatile Organics [%]	< 7
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	95.50 ± 0.01
▪ Brightness (ISO) [%]	96	▪ Moisture [%]	3.60
▪ Roughness [µm]	125	▪ Conductivity [W/m.K]	0.004
▪ Dust [mg/m^{-3}]	0.29	▪ Viscosity (max. sol.) [Pa.s]	0.991
▪ Scott Bonding [J/m^2]	6.5	▪ Density [g/dL]	214.42
▪ Odour	LOW	▪ Flammability in air [g/m^3]	N/A
SAFETY			
▪ PPE Req.	Respirator, safety goggles, gloves	▪ Storage Label	N/A
SUPPLIER INFORMATION			
▪ Supplier Company Name	AOP Ltd.	▪ Cost [$/t]	890.0
▪ Supply History			
Current supplier (5+ yrs)		2012: 10.5 kt ($9.35 M)	
		2013: 10.8 kt ($9.61 M)	
		2014: 10.3 kt ($9.17 M)	
		2015: 8.7 kt ($7.74 M)	
		2016: 10.0 kt ($8.90 M)	

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: LS Version Date: 31/01/2011

MSS-001		HANDOUT #4.1		Ci
Doc. Version:	2.1		Controller:	Raw Ingred.

1. PURPOSE

1.1 This Material Specifications Sheet outlines the acceptable ranges (displayed as "x.xx – y.yy" OR "< x.xx" OR "> x.xx") of chemical and physical properties.

1.2 Properties should be optimised by being at the HIGH, LOW, or MIDDLE of the acceptable ranges, where possible. Properties will have [HIGH], or [LOW], or [MID] to indicate range preference.

IDENTIFICATION			
▪ Internal Code		▪ Supplier Product Name	
▪ Empirical Formula		▪ Data Sheet Prep. Date	
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	6.5 – 7.5 [MID]	▪ Partition K(C_8 | H) [unit]	15 – 20 [LOW]
▪ Heat of Dissol. [kJ/kg]	0.300 – 0.400 [LOW]	▪ Toxicity (STEL) [g/kg.hr]	< 1.50E-08 [LOW]
▪ Melting Pt. [ºC]	1750 – 1850 [HIGH]	▪ Toxicity (LOEC) [g/kg.hr]	< 5.00E-11 [LOW]
▪ Solubility in Water [kg/L]	< 5 [LOW]	▪ Volatile Organics [%]	< 10 [LOW]
PHYSICAL PROPERTIES			
▪ Physical Form		▪ Purity [%]	> 92.5 [HIGH]
▪ Brightness (ISO) [%]	> 90 [HIGH]	▪ Moisture [%]	< 5.00 [LOW]
▪ Roughness [µm]	> 100 [HIGH]	▪ Conductivity [W/m.K]	< 0.005 [LOW]
▪ Dust [mg/m^3]	< 0.30 [LOW]	▪ Viscosity (max. sol.) [Pa.s]	0.85 – 1.00 [LOW]
▪ Scott Bonding [J/m^2]	6.00 – 7.00 [LOW]	▪ Density [g/dL]	205 – 215 [HIGH]
▪ Odour	NONE or LOW	▪ Flammability in air [g/m^3]	< 1500 [LOW]
SAFETY			
▪ PPE Req.		▪ Storage Label	
SUPPLIER INFORMATION			
▪ Supplier Company Name		▪ Cost [$/t]	
▪ Supply History			

Authorised: JW Version Date: 19/10/2012

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SECTION 3

- **Handout #1.7 (MDS-772)**
- **Handouts #2.1 – 2.9 (TES-001 – TES-009)**
- **Handout #3.1 (BOO-001)**
- **Handout #5.1 (FOR-001)**

MDS-772		HANDOUT #1.7		Ci
Doc. Version:	3.3		Controller:	Qual. Contr.

IDENTIFICATION			
▪ Internal Code	MDS-772	▪ Formulation	FOR-001
		▪ Data Sheet Prep. Date	10/10/2003
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]		▪ Partition K(C_8|H) [unit]	N/A
▪ Heat of Dissol. [kJ/kg]	N/A	▪ Toxicity (STEL) [g/kg.hr]	
▪ Melting Pt. [ºC]	N/A	▪ Toxicity (LOEC) [g/kg.hr]	
▪ Solubility in Water [kg/L]	N/A	▪ Volatile Organics [%]	
PHYSICAL PROPERTIES			
▪ Physical Form	SLURRY	▪ Purity [%]	N/A
▪ Brightness (ISO) [%]		▪ Moisture [%]	
▪ Roughness [μm]		▪ Conductivity [W/m.K]	1.00
▪ Dust [mg/m³]	N/A	▪ Viscosity (max. sol.) [Pa.s]	
▪ Scott Bonding [J/m²]	N/A	▪ Density [g/dL]	
▪ Odour		▪ Flammability in air [g/m³]	N/A
SAFETY			
▪ PPE Req.	Gloves	▪ Storage Label	Nil

Note: This product is formulated using FOR-001.

Authorised: KW Version Date: 26/07/2017

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TES-001 (pH Test)	HANDOUT #2.1			Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **pH TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- pH / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**pH TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 15 min	pH Meters: 15 min

3.2 This test requires: 50 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**pH TEST**)
  - Materials cost: $ 1 per gram
  - Equipment cost: $ 50

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

TES-001 (pH Test)		HANDOUT #2.1		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

5.1 None

[TESTING PHASE]

15 min (Benches)

5.2 Weigh out 50.0 grams of the sample, precisely.

For LIQUID, go to Step 5.4.
For POWDER/SLURRY/EMULSION, go to Step 5.3.

5.3 **FOR POWDER/SLURRY/EMULSION ONLY**
Dissolve/disperse this sample into 50.0 grams of deionised water. Stir thoroughly to dissolve/disperse sample.

15 min (pH Meters)

5.4 Rinse any available pH meter probe with deionised water.

5.5 Place probe in sample solution and press the [MEASURE] button.

5.6 Reading will stabilise within 15 seconds. When reading stabilises, read pH value from the display.

5.7 Rinse probe and return probe to storage solution.

TES-002 (Solubility Test)		HANDOUT #2.2		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **SOLUBILITY TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Solubility in Water [kg/L] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**SOLUBILITY TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 10 min	Mixers: 20 min

3.2 This test requires: 100 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**SOLUBILITY TEST**)
  - Materials cost: $ 5 per gram
  - Equipment cost: $ 150

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

TES-002 (Solubility Test)		HANDOUT #2.2		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
	5.1	None
		[TESTING PHASE]
10 min (Benches)	5.2	Weigh out 100.0 grams of sample, precisely.
	5.3	Allow sample to cool to room temperature.
	5.4	Measure 100.0 mL of deionised water, at 20ºC.
	5.5	Place water on laboratory scale with mixer and note the initial weight.
20 min (Mixers)	5.6	Using any available mixer, add dried sample slowly to the water, mixing continuously. This process will take 10 minutes of constant addition.
	5.7	Continue sample addition until a visible solid can be seen at the top or bottom of the water. This solution should be mixed for 5 minutes to ensure that no more dissolution occurs.
	5.8	Note the final weight (grams) and calculate the solubility as: $\frac{(m_f - m_i)}{100.0}$

TES-003 (Drying Test)		HANDOUT #2.3		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DRYING TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Melting Point [ºC] / 0.0 / ± 0.1
- Purity [%] / 0.00 / ± 0.01
- Moisture [%] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**DRYING TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 15 min	Ovens: 45 min

3.2 This test requires: 100 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**DRYING TEST**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 100

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

TES-003 (Drying Test)		HANDOUT #2.3		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

5.1 None

[TESTING PHASE]

15 min (Benches)

5.2 Weigh out 50.0 grams of the sample, precisely.

5.3 Place sample on to foil tray and spread evenly.

5.4 Weigh tray with sample and record initial weight.

45 min (Ovens)

5.5 Place tray in any available oven at 120ºC for 15 minutes.

5.6 While drying is occurring, clean preparation area thoroughly.

5.7 Remove tray and let sample return to room temperature.

5.8 Weigh dried sample with tray and record final weight. Calculate the moisture content as:

$$\frac{(m_f - m_i)}{100}$$

5.9 Repeat steps 5.2 and 5.3.

5.10 Calibrate the melting point apparatus before each test to ensure accurate readings.

5.11 Place tray in controlled oven, starting at 100ºC with heat gradient set at 2ºC/min. Press [START] to begin melting point test.

5.12 After 25 minutes, read melting point reading from front display.

5.13 While melting is occurring, clean area thoroughly and prepare for removal of sample(s).

5.14 Remove foil tray and dispose.

TES-004 (Optical Test)		**HANDOUT #2.4**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **OPTICAL TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Brightness (ISO) [%] / 0 / ± 2
- Roughness [µm] / 0 / ± 10
- Dust [mg/m³] / 0.00 / ± 0.05

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRYING**)		Testing (**OPTICAL TEST**)	
Benches: 15 min	Ovens: 45 min	Benches: 0 min	Microscope: 30 min

3.2 This test requires: 50 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRYING**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200

- Testing (**OPTICAL TEST**)
  - Materials cost: $ 10 per gram
  - Equipment cost: $ 150

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- Microscope. Equipment must booked.

TES-004 (Optical Test)	HANDOUT #2.4		Ci
Doc. Version:	1.0	Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
15 min (Benches)	5.1	Weigh out 50.0 grams of the sample, precisely.
	5.2	Place sample on to foil tray and spread evenly.
45 min (Ovens)	5.3	Wait for preheating. Spread sample thinly on plate & prepare documentation.
	5.4	Insert tray in any available oven.
	5.5	*Must wait for 30 minutes.*
		You may pause the process here
		[TESTING PHASE]
30 min (Microscope)	5.6	Clean microscope light emitter.
	5.7	Open rear sample hatch.
	5.8	Insert microscopy tubule.
	5.9	On the front panel, set-up Brightness, Roughness and Dust Testing schema. This can be selected using the keypad with the following keystrokes; [UP], [UP], [DOWN], [DOWN], [LEFT], [RIGHT], [LEFT], [RIGHT], [A], [B].
	5.10	Press [START].
	5.11	*Must wait for 30 minutes.*
0 min (Microsc.)	5.12	Read results from front panel.
	5.13	Remove microscopy tubule from rear hatch.
	5.14	Clean microscope light emitter.

Authorised: PG Version Date: 15/08/2012

TES-005 (Dissolution Test)		HANDOUT #2.5		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DISSOLUTION TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- pH / 0.00 / ± 0.01
- Heat of Dissolution [kJ/kg] / 0.00 / ± 0.01
- Solubility in Water [kg/L] / 0.00 / ± 0.01
- Partition K(C_8|H) / 0 / ± 0.5
- Odour
- Conductivity / 0.000 / ± 0.001
- Viscosity (max. sol.) [Pa.s] / 0.000 / ± 0.001

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**SHEAR MIXING**)		Testing (**DISSOLUTION TEST**)	
Benches: 0 min	High Shear Mixer: 30 min	Benches: 30 min	Mixers: 30 min

3.2 This test requires: 100 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**SHEAR MIXING**)
  - Materials cost: $ 3.5 per gram
  - Equipment cost: $ 300

- Testing (**DISSOLUTION TEST**)
  - Materials cost: $ 5 per gram
  - Equipment cost: $ 150

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- High Shear Mixer. Equipment must be booked.

TES-005 (Dissolution Test)		HANDOUT #2.5		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

30 min (H. Shear Mixer)

5.1 Weigh out 100.0 grams of the sample, precisely.

5.2 Ensure that high shear mixer bowl is clean and free from contamination and moisture.

5.3 Add sample to high shear mixer bowl.

5.4 Set to highest shear setting and press [START].

5.5 *Must wait for 30 minutes.*

You may pause the process here

[TESTING PHASE]

30 min (Benches)

5.6 Take 25.0 grams of the sheared sample and place it in a crucible mixer.

5.7 Set up a drip-pipe with a water header at an addition rate of 2 mL/min.

5.8 Open drip-pipe outlet until all of the sample is dissolved.

5.9 Read the heat of dissolution from the front meter on the crucible mixer.

5.10 Carefully sniff the product and note any detectable odour.

5.11 Attach the pH probe to any avilable crucible mixer.

5.12 Place probe in the sample and read result from the front panel on the crucible mixer.

You may pause the process here

30 min (Mixers)

5.13 Repeat steps 5.10 and 5.11 for the Solubility probe.

5.14 Repeat steps 5.10 and 5.11 for the Conductivity probe.

5.15 Repeat steps 5.10 and 5.11 for the Viscosity probe.

5.16 Dispose of sample.

5.17 Repeat steps 5.6 – 5.10 using a 25%/75% octanol/water solution.

5.18 Attach Partition probe to the crucible mixer.

5.19 Place probe in sample and read result from the front panel on the crucible mixer.

5.20 Dispose of sample.

Authorised: PG   Version Date: 15/08/2012

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TES-006 (Powder Flow Test)	HANDOUT #2.6		Ci	
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **POWDER FLOW TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Dust [mg/m³] / 0.000 / ± 0.001
- Scott Bonding [J/m²] / 0.000 / ± 0.001
- Flammability in Air [g/m³] / 0 / ± 10
- PPE Requirement

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**SIEVING**)		Testing (**POWDER FLOW TEST**)	
Benches: 0 min	Sieve Rack: 60 min	Benches: 0 min	Free-Flow Tester: 60 min

3.2 This test requires: 100 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**SIEVING**)
  - Materials cost: $ 7 per gram
  - Equipment cost: $ 400

- Testing (**POWDER FLOW TEST**)
  - Materials cost: $ 1 per gram
  - Equipment cost: $ 50

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- Sieve Rack. Equipment must be booked.
- Free-Flow Tester. Equipment must be booked.

TES-006 (Powder Flow Test)		**HANDOUT #2.6**		
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
60 min (Sieve Rack)	5.1	Open sieving apparatus.
	5.2	Ensure that sieve meshes are clear from debris or residue.
	5.3	Insert calibration powder into top sieve mesh. Close apparatus.
	5.4	Run sieve rack by pressing [CALIBRATE].
	5.5	At end of calibration, ensure that all powder has fallen through the bottom sieve.
	5.6	Remove remaining powder and clear meshes.
	5.7	Weigh out 100.0 grams of sample, precisely.
	5.8	Insert sample into top sieve mesh.
	5.9	Run sieve rack at 60 rpm.
	5.10	*Must wait for 30 minutes.*
		You may pause the process here
0 min (Free-Flow Tester)	5.11	Collect powder from bottom sieve.
		[TESTING PHASE]
	5.12	Fill free-flow tester sample tube with approximately 10 grams of powder, ensuring that no air bubbles are present. Please note that the exact mass of powder does not need to be recorded and has no effect on the results of the free-flow powder testing.
60 min (Free-Flow Tester)	5.13	Introduce the sample tube to the free-flow powder tester.
	5.14	On the front panel, select [DUSTING], [BONDING] and [FLAME]. Then press [START].
	5.15	After approximately 10 minutes, record the results from the front panel.
	5.16	Remove and discard sample tube.
	5.17	Repeat steps 5.12 – 5.16 until all of the sieved sample has been consumed.
	5.18	Find the mean average results of each test and record these as the final figures.
	5.19	For any dust result greater than 0.01 mg/m³, record the PPE requirement as "Gloves, Dust Mask"

TES-007 (Stability Test)		HANDOUT #2.7		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **STABILITY TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Toxicity (STEL) [g/kg.hr] / 0.00E-09 / ± 0.01E-09
- Toxicity (LOEC) [g/kg.hr] / 0.00E-11 / ± 0.01E-11
- Volatile Organics [%] / 0.0 / ± 0.1
- Odour
- Density [g/dL] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**SHEAR MIXING**)		Testing (**STABILITY TEST**)	
Benches: 0 min	High Shear Mixer: 30 min	Benches: 0 min	Advanced Stabiliser: 60 min

3.2 This test requires: 150 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**SHEAR MIXING**)
  - Materials cost: $ 3.5 per gram
  - Equipment cost: $ 300

- Testing (**STABILITY TEST**)
  - Materials cost: $ 10 per gram
  - Equipment cost: $ 450

4. REQUIRED EQUIPMENT

4.1 This test requires the following specialised equipment:

- High Shear Mixer. Equipment must booked.
- Advanced Stabiliser. Equipment must booked.

TES-007 (Stability Test)		**HANDOUT #2.7**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
30 min (H. Shear Mixer)	5.1	Weigh out 150.0 grams of the sample, precisely.
	5.2	Ensure that high shear mixer bowl is clean and free from contamination and moisture.
	5.3	Add sample to high shear mixer bowl.
	5.4	Set to highest shear setting and press [START].
	5.5	*Must wait for 30 minutes.*
		You may pause the process here
		[TESTING PHASE]
60 min (Adv. Stabiliser)	5.6	Separate sample into equal 50.0 gram amounts.
	5.7	Place each 50.0 gram sample into a 100 mL conical flask.
	5.8	Add 25.0 mL of deionised water into two conical flasks.
	5.9	Stir to dissolve sample.
	5.10	Carefully sniff the dissolved samples and note any detectable odour.
	5.11	Cover the two flasks containing the dissolved samples with Protex film to stop air transfer into the flask.
	5.12	Place all flasks in the advanced stabiliser
	5.13	In the uncovered flask (non-dissolved sample), place the sampling probe.
	5.14	Close the top flap and start the machine pump and heater.
	5.15	*Must wait for 30 minutes.*
0 min (Adv. Stab.)	5.16	Record the STEL and LOEC measurements from the front panel, and the density from the secondary panel.
	5.17	Carefully observe the two covered samples for any discolouration.
	5.18	Dispose of all samples.

TES-008 (Slurry Test)		**HANDOUT #2.8**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **SLURRY TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Empirical Formula
- Heat of Dissolution [kJ/kg] / 0.00 / ± 0.01
- Odour
- Purity [%] / 0.00 / ± 0.01
- Viscosity (max. sol.) [Pa.s] / 0.000 / ± 0.001

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRY** & **SHEAR MIXING**)			Testing (**SLURRY TEST**)	
Benches: 15 min	Ovens: 45 min	High Shear Mixer: 30 min	Benches: 30 min	Restrict-Flow Tester: 150 min

3.2 This test requires: 200 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRY**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200
- Preparation (**SHEAR MIXING**)
  - Materials cost: $ 3.5 per gram
  - Equipment cost: $ 300
- Testing (**SLURRY TEST**)
  - Materials cost: $ 8 per gram
  - Equipment cost: $ 600

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- High Shear Mixer. Equipment must be booked.
- Restrict-Flow Tester. Equipment must be booked.

TES-008 (Slurry Test)		HANDOUT #2.8		
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

		[PREPARATION PHASE]
15 min (Benches)	5.1	Weigh out 200.0 grams of the sample, precisely.
	5.2	Place sample on to two foil trays and spread evenly.
45 min (Ovens)	5.3	Preheat any available oven to 180ºC.
	5.4	Place tray in oven.
	5.5	*Must wait for 30 minutes.*
		You may pause the process here
30 min (H. Shear Mixer)	5.6	Remove tray and let sample return to room temperature.
	5.7	Add sample to high shear mixer bowl.
	5.8	Set to highest shear setting and press [START]
	5.9	*Must wait for 30 minutes.*
		You may pause the process here
		[TESTING PHASE]
30 min (Benches)	5.10	Transfer sheared sample to 2L glass container.
	5.11	Slowly add deionised water while constantly stirring until no more dry powder can be seen.
		You may pause the process here
150 min (R. Flow Tester)	5.12	Carefully transfer all of this into the top hopper of the restrict-flow meter.
	5.13	Select "Testing Parameters: 2" using the front keypad.
	5.14	Press [START].
	5.15	*Must wait for 120 minutes.*
0 min (R. Flow)	5.16	Note down all results from the front panel.
	5.17	Shutdown machine.

TES-009 (Dry Powder Test)	HANDOUT #2.9			Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DRY POWDER TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY

1.3 Refer to the appropriate MDS to find the material's Physical Form.

1.4 The FLOW DETECTOR undertakes eight (8) separate tests, using eight (8) separate detectors. Results for each test should be considered independently.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Toxicity (STEL) [g/kg.hr] / 0.00E-09 / ± 0.01 E-09
- Toxicity (LOEC) [g/kg.hr] / 0.00E-11 / ± 0.01E-11
- Brightness (ISO) [%] / 0 / ± 1
- Roughness [µm] / 0 / ± 5
- Dust [mg/m³] / 0.00 / ± 0.05
- Scott Bonding [J/m²] / 0.000 / ± 0.001
- Moisture [%] / 0.00 / ± 0.01
- Density [g/dL] / 0.00 / ± 0.01
- Flammability in Air [g/m³] / 0 / ± 10
- PPE Requirement

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRY** & **SIEVE**)			Testing (**DRY POWDER TEST**)	
Benches: 15 min	Ovens: 45 min	Sieve Rack: 60 min	Benches: 30 min	Flow Detector: 240 min

3.2 This test requires: 50 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRY**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200
- Preparation (**SIEVE**)
  - Materials cost: $ 7 per gram
  - Equipment cost: $ 400
- Testing (**DRY POWDER TEST**)
  - Materials cost: $ 35 per gram
  - Equipment cost: $ 750

4. REQUIRED EQUIPMENT

4.1 This test requires the following specialised equipment:

- Sieve Rack. Equipment must be booked.
- Flow Detector. Equipment must be booked.

TES-009 (Dry Powder Test)		**HANDOUT #2.9**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

15 min (Benches)

5.1 Weigh out 50.0 grams of the sample, precisely.

5.2 Place sample on to two foil trays and spread evenly.

45 min (Ovens)

5.3 Preheat any available oven to $180^{\circ}C$. Then place tray in oven.

5.4 *Must wait for 30 minutes.*

You may pause the process here

60 min (Sieve Rack)

5.5 Ensure that sieve meshes are clear from debris or residue.

5.6 Insert calibration powder into top sieve mesh. Close apparatus.

5.7 Run sieve rack by pressing [CALIBRATE].

5.8 Check meshes and remove powder.

5.9 Weigh out 100.0 grams of sample, precisely and insert into top sieve mesh.

5.10 Run sieve rack at 60 rpm.

5.11 *Must wait for 30 minutes.*

You may pause the process here

[TESTING PHASE]

30 min (Benches)

5.12 Transfer sieved sample to 2L glass container.

5.13 Slowly add deionised water while constantly stirring until no more dry powder can be seen.

210 min (Flow Detector)

5.14 Carefully transfer all of this into the top hopper of the flow detector.

5.15 Press [START].

5.16 *Must wait for 180 minutes.*

You may pause the process here

30 min (Flow Detector)

5.17 Note down all results from the front panel.

5.18 For any dust result greater than 0.01 mg/m^3, record the PPE requirement as "Gloves, Dust Mask"

5.19 Clean-up and shutdown machine.

6. SAFETY NOTES

6.1 Please familiarise yourself with the following safety notes:

- Specialised equipment with multiple tests conducted [1]
- Ensure appropriate training [2]
- Equipment will always give the result of NO HALFLIFE [3]

1. The Flow Detector contains eight (8) separate testing apparatus. The results of each test should be considered separately.
2. Please ensure that you are appropriately inducted and authorised to use this equipment.
3. This equipment is not suitable for use with radioactive material.

Authorised: PG Version Date: 15/08/2012

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BOO-001 (Booking Schedule)		HANDOUT #3.1		Ci
Doc. Version:	1.0		Controller:	Quality Control

Booking Schedule (VALID FOR THE NEXT 3 WEEKS)

Key:
Busy
Free

NOTE: Equipment can NOT be run overnight. All equipment will be emptied and cleaned at 5 PM each day.

Equipment	Booking Req.?	Mon 9-9.30	Mon 9.30-10	Mon 10-10.30	Mon 10.30-11	Mon 11-11.30	Mon 11.30-12	Mon 12-12.30	Mon 12.30-1	Mon 1-1.30	Mon 1.30-2	Mon 2-2.30	Mon 2.30-3	Mon 3-3.30	Mon 3.30-4	Mon 4-4.30	Mon 4.30-5
Adv. Stabiliser	YES	Free	Free	Free	Free	Busy	Free	Free	Free	Busy	Free	Busy	Free	Busy	Busy	Busy	Busy
Flow Detector	YES	Free	Busy	Busy	Busy	Busy	Free	Free	Free	Busy	Busy	Busy	Free	Free	Busy	Busy	Busy
Free-flow Tester	YES	Free	Busy	Busy	Busy	Free	Free	Busy	Busy	Busy	Free	Free	Busy	Busy	Free	Free	Free
High Shear Mixer	YES	Busy	Busy	Busy	Free	Free	Busy	Free	Busy	Free	Free	Busy	Free	Free	Free	Free	Busy
Microscope	YES	Busy	Busy	Free	Free	Busy	Free	Free	Busy	Free	Busy	Free	Busy	Free	Busy	Busy	Busy
Restrict-flow Tester	YES	Free	Busy	Busy	Busy	Busy	Free	Free	Free	Free	Free	Busy	Busy	Busy	Busy	Busy	Busy
Sieve Rack	YES	Busy	Free	Free	Busy	Busy	Free	Free	Busy	Free	Free	Busy	Free	Busy	Busy	Busy	Busy

Equipment	Booking Req.?	Tue 9-9.30	Tue 9.30-10	Tue 10-10.30	Tue 10.30-11	Tue 11-11.30	Tue 11.30-12	Tue 12-12.30	Tue 12.30-1	Tue 1-1.30	Tue 1.30-2	Tue 2-2.30	Tue 2.30-3	Tue 3-3.30	Tue 3.30-4	Tue 4-4.30	Tue 4.30-5
Adv. Stabiliser	YES	Free	Free	Busy	Free	Busy	Free	Free	Busy	Free	Free	Busy	Free	Busy	Busy	Busy	Busy
Flow Detector	YES	Free	Busy	Busy	Busy	Free	Busy	Busy	Busy	Free	Free	Busy	Free	Free	Busy	Free	Busy
Free-flow Tester	YES	Busy	Free	Free	Busy	Busy	Free	Free	Busy	Busy	Free	Free	Busy	Free	Free	Free	Busy
High Shear Mixer	YES	Busy	Busy	Busy	Busy	Free	Free	Free	Busy	Busy	Free	Busy	Free	Free	Busy	Free	Free
Microscope	YES	Busy	Busy	Busy	Free	Free	Busy	Busy	Free	Busy	Busy	Busy	Free	Free	Busy	Free	Free
Restrict-flow Tester	YES	Free	Free	Free	Free	Free	Busy	Free	Busy	Busy	Busy	Free	Free	Free	Free	Free	Free
Sieve Rack	YES	Busy	Busy	Busy	Free	Free	Busy	Free	Busy	Free	Free	Busy	Busy	Busy	Busy	Free	Busy

Equipment	Booking Req.?	Wed 9-9.30	Wed 9.30-10	Wed 10-10.30	Wed 10.30-11	Wed 11-11.30	Wed 11.30-12	Wed 12-12.30	Wed 12.30-1	Wed 1-1.30	Wed 1.30-2	Wed 2-2.30	Wed 2.30-3	Wed 3-3.30	Wed 3.30-4	Wed 4-4.30	Wed 4.30-5
Adv. Stabiliser	YES	Busy	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Flow Detector	YES	Free	Free	Free	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Free-flow Tester	YES	Free	Busy	Busy	Busy	Free	Free	Free	Free	Free	Free	Busy	Free	Free	Busy	Free	Free
High Shear Mixer	YES	Busy	Free	Free	Free	Busy	Busy	Busy	Free	Free	Free	Busy	Busy	Busy	Busy	Busy	Busy
Microscope	YES	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Restrict-flow Tester	YES	Free	Free	Free	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Sieve Rack	YES	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Busy	Busy	Busy	Busy	Busy

Authorised: JG

Version Date: 12/04/2017

BOO-001 (Booking Schedule)		HANDOUT #3.1		Ci
Doc. Version:	1.0		Controller:	Quality Control

Equipment	Booking Req.?	Thu 9-9.30	Thu 9.30-10	Thu 10-10.30	Thu 10.30-11	Thu 11-11.30	Thu 11.30-12	Thu 12-12.30	Thu 12.30-1	Thu 1-1.30	Thu 1.30-2	Thu 2-2.30	Thu 2.30-3	Thu 3-3.30	Thu 3.30-4	Thu 4-4.30	Thu 4.30-5
Adv. Stabiliser	YES	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Busy	Busy	Busy	Busy	Busy
Flow Detector	YES	Free	Free	Free	Free	Free	Busy	Busy	Busy	Busy	Busy	Free	Free	Free	Free	Busy	Busy
Free-flow Tester	YES	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy
High Shear Mixer	YES	Free	Free	Free	Free	Busy	Busy	Busy	Free	Free	Free	Free	Busy	Free	Busy	Free	Busy
Microscope	YES	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy	Busy
Restrict-flow Tester	YES	Free	Free	Free	Free	Free	Free	Free	Busy	Free	Free	Free	Free	Free	Free	Busy	Busy
Sieve Rack	YES	Busy	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free

Equipment	Booking Req.?	Fri 9-9.30	Fri 9.30-10	Fri 10-10.30	Fri 10.30-11	Fri 11-11.30	Fri 11.30-12	Fri 12-12.30	Fri 12.30-1	Fri 1-1.30	Fri 1.30-2	Fri 2-2.30	Fri 2.30-3	Fri 3-3.30	Fri 3.30-4	Fri 4-4.30	Fri 4.30-5
Adv. Stabiliser	YES	Busy	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Flow Detector	YES	Free	Free	Free	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Free-flow Tester	YES	Free	Busy	Busy	Busy	Free	Free	Free	Free	Free	Free	Busy	Free	Free	Busy	Free	Free
High Shear Mixer	YES	Free	Free	Free	Free	Free	Free	Busy	Busy	Busy	Free	Free	Free	Free	Busy	Free	Free
Microscope	YES	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Restrict-flow Tester	YES	Free	Free	Free	Busy	Busy	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free
Sieve Rack	YES	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Free	Busy	Busy	Busy	Busy	Busy

Blank Schedule (for planning)

	9-9.30	9.30-10	10-10.30	10.30-11	11-11.30	11.30-12	12-12.30	12.30-1	1-1.30	1.30-2	2-2.30	2.30-3	3-3.30	3.30-4	4-4.30	4.30-5
Monday																
Tuesday																
Wednesday																
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Friday																

Authorised: JG

Version Date: 12/04/2017

FOR-001 (Product Formulation)		HANDOUT #5.1		Ci
Doc. Version:	3.5		Controller:	Formulation

1. PURPOSE

1.1 This is the process to formulate Corporation Inc.'s flagship product.

1.2 NOTE: Changing the batch size (amount of product formulated) will have no effect on the duration and no effect on the equipment cost.

2. PROCESS OUTLINE

2.1 The formulating is a two-step process; (i) the base ingredients are combined, (ii) additive ingredients are added to make the final product.

3. MATERIALS REQUIRED

3.1 Required ingredients (1 can = 500g):

		Batch size:	
		500	grams
Raw Material Description	*Supplier*	*%w/w*	*Weight (g) (±1%)*
BASE INGREDIENTS (total: 490 g)			
Powder (P-1522)	Millings	10	50 ± 0.50
Powder (P-1601)	Millings	20	100 ± 1.00
Hydroxy-glycol (S-1135)	JJG	10	50 ± 0.50
Water	Mains MQ	58	290 ± 2.90
ADDITIVE INGREDIENTS (total: 10 g)			
Powder (LD-5528)	AOP Ltd.	1	5 ± 0.05
Powder (JT-7735)	Millings	0.6	3 ± 0.03
Sodium phenylbutyrate (S-1136)	Norotyne	0.4	2 ± 0.02
	Total:	100%	500g

3.2 Required ingredients have the following effects:

BASE INGEDIENTS

- Powder (P-1522) [main ingredient 1]
- Powder (P-1601) [main ingredient 2]
- Hydroxy-glycol (S-1135) [increases the stability of the product]
- Water [solvent; allows powders to react]

ADDITIVE INGREDIENTS

- Powder (LD-5528) [increase the brightness of product]
- Powder (JT-7735) [prevents reactions occurring in product]
- Sodium phenylbutyrate (S-1136) [adjusts the scent of product]

Authorised: HB Version Date: 01/10/2005

Page 1 of 2

FOR-001 (Product Formulation)		HANDOUT #5.1		Ci
Doc. Version:	3.5		Controller:	Formulation

4. DURATION & COST

4.1 This process will take the following duration:

Preparation		Combining	
Bench: 30 min	Mixer: 30 min	Bench: 10 min	Mixer: 50 min

4.2 This test will cost:

- **Preparation step:**
  - Materials cost: $ 0.5 per gram of base made
  - Other costs: $ 200
- **Combining step:**
  - Materials cost: $ 36.75 per gram of additive used
  - Other costs: $ 50

5. REQUIRED EQUIPMENT BOOKING

5.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

6. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

30 min (Bench)	5.1	Weigh out P-1522 and P-1601 precisely.
	5.2	Combine roughly in a 5 L stainless steel bowl.
	5.3	Transfer these powders into the mixer.
30 min (Mixer	5.4	Slowly add water, while mixing at 60 rpm.
	5.5	Continue mixing for an extra 10 minutes.
	5.6	Add S-1135.

You may pause the process here

[COMBINING PHASE]

60 min (Bench & Mixer)	5.7	Sieve LD-5528 on to a glass plate.
	5.8	Sieve JT-7735 on to a glass plate.
	5.9	Slowly add LD-5528 and JT-7735 to mixer.
	5.10	Add S-1136 slowly to the mixer.
	5.11	Mix thoroughly for 45 minutes
	5.12	Transfer mixture to can.

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Measuring Industry Critical Abilities

SECTION 4

- **Handout #5.1 (FOR-001)**
- **Handout #6.1 (BAT-001)**

FOR-001 (Product Formulation)	HANDOUT #5.1		Ci	
Doc. Version:	3.5		Controller:	Formulation

1. PURPOSE

1.1 This is the process to formulate Corporation Inc.'s flagship product.

1.2 NOTE: Changing the batch size (amount of product formulated) will have no effect on the duration and no effect on the equipment cost.

2. PROCESS OUTLINE

2.1 The formulating is a two-step process; (i) the base ingredients are combined, (ii) additive ingredients are added to make the final product.

3. MATERIALS REQUIRED

3.1 Required ingredients (1 can = 500g):

		Batch size: 500	grams
Raw Material Description	*Supplier*	*%w/w*	*Weight (g) (±1%)*
BASE INGREDIENTS (total: 490 g)			
Powder (P-1522)	Millings	10	50 ± 0.50
Powder (P-1601)	Millings	20	100 ± 1.00
Hydroxy-glycol (S-1135)	JJG	10	50 ± 0.50
Water	Mains MQ	58	290 ± 2.90
ADDITIVE INGREDIENTS (total: 10 g)			
Powder (LD-5528)	AOP Ltd.	1	5 ± 0.05
Powder (JT-7735)	Millings	0.6	3 ± 0.03
Sodium phenylbutyrate (S-1136)	Norotyne	0.4	2 ± 0.02
	Total:	100%	500g

3.2 Required ingredients have the following effects:

BASE INGEDIENTS

- Powder (P-1522) [main ingredient 1]
- Powder (P-1601) [main ingredient 2]
- Hydroxy-glycol (S-1135) [increases the stability of the product]
- Water [solvent; allows powders to react]

ADDITIVE INGREDIENTS

- Powder (LD-5528) [increase the brightness of product]
- Powder (JT-7735) [prevents reactions occurring in product]
- Sodium phenylbutyrate (S-1136) [adjusts the scent of product]

FOR-001 (Product Formulation)		HANDOUT #5.1		Ci
Doc. Version:	3.5		Controller:	Formulation

4. DURATION & COST

4.1 This process will take the following duration:

Preparation		Combining	
Bench: 30 min	Mixer: 30 min	Bench: 10 min	Mixer: 50 min

4.2 This test will cost:

- **Preparation step:**
  - Materials cost: $ 0.5 per gram of base made
  - Other costs: $ 200
- **Combining step:**
  - Materials cost: $ 36.75 per gram of additive used
  - Other costs: $ 50

5. REQUIRED EQUIPMENT BOOKING

5.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

6. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

30 min (Bench)

5.1 Weigh out P-1522 and P-1601 precisely.
5.2 Combine roughly in a 5 L stainless steel bowl.
5.3 Transfer these powders into the mixer.

30 min (Mixer

5.4 Slowly add water, while mixing at 60 rpm.
5.5 Continue mixing for an extra 10 minutes.
5.6 Add S-1135.

You may pause the process here

[COMBINING PHASE]

60 min (Bench & Mixer)

5.7 Sieve LD-5528 on to a glass plate.
5.8 Sieve JT-7735 on to a glass plate.
5.9 Slowly add LD-5528 and JT-7735 to mixer.
5.10 Add S-1136 slowly to the mixer.
5.11 Mix thoroughly for 45 minutes
5.12 Transfer mixture to can.

BAT-001	HANDOUT #6.1			
Doc. Version:	1.3		Controller:	Prod. & Maint.

Date: 10/10/2017

<table>
<tr><th>Batch No.</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th></tr>
<tr><td>Production Overseer (initials)</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td><td>AP</td></tr>
<tr><td>Product</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-001</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td><td>FOR-003</td></tr>
<tr><td>Warehouse Bay</td><td>1</td><td>1</td><td>1</td><td>1</td><td>2</td><td>2</td><td>2</td><td>3</td><td>3</td><td>3</td><td>3</td><td>8</td><td>8</td><td>8</td><td>9</td><td>9</td><td>9</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Hopper Number</td><td>1</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>2</td><td>3</td><td>1</td><td>2</td><td>2</td><td>1</td><td>2</td><td>2</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td>Total mass added (kg)</td><td>1136</td><td>1058</td><td>1152</td><td>1043</td><td>1082</td><td>1009</td><td>1032</td><td>1041</td><td>1094</td><td>1120</td><td>1131</td><td>1065</td><td>1032</td><td>1113</td><td>1143</td><td>1044</td><td>1156</td><td>1054</td><td>1074</td><td>1101</td></tr>
<tr><td>Temp. (°C)</td><td>7.3</td><td>7.2</td><td>7.5</td><td>6.8</td><td>6.9</td><td>7.0</td><td>7.1</td><td>7.4</td><td>7.6</td><td>7.7</td><td>8.1</td><td>12.2</td><td>12.6</td><td>13.7</td><td>15.4</td><td>17.2</td><td>17.8</td><td>18.9</td><td>20.1</td><td>19.7</td></tr>
<tr><td>Rel. humidity (%)</td><td>21</td><td>17</td><td>19</td><td>22</td><td>16</td><td>23</td><td>16</td><td>17</td><td>19</td><td>18</td><td>20</td><td>14</td><td>13</td><td>14</td><td>13</td><td>13</td><td>12</td><td>13</td><td>14</td><td>12</td></tr>
<tr><td>Milling speed (RPM)</td><td>1103</td><td>1112</td><td>1115</td><td>1101</td><td>1108</td><td>998</td><td>1113</td><td>1112</td><td>1098</td><td>1100</td><td>1112</td><td>1135</td><td>1132</td><td>1128</td><td>1129</td><td>1130</td><td>1134</td><td>1135</td><td>1128</td><td>1131</td></tr>
<tr><td>Base ingredient 1 added (kg)</td><td>114.5</td><td>106</td><td>114.1</td><td>105.2</td><td>108.3</td><td>101.7</td><td>102.1</td><td>103.8</td><td>110.4</td><td>112.7</td><td>113.2</td><td>115.3</td><td>113.3</td><td>121.8</td><td>125.4</td><td>113.6</td><td>126.5</td><td>115.1</td><td>118.5</td><td>122.9</td></tr>
<tr><td>Base ingredient 2 added (kg)</td><td>228.6</td><td>209.9</td><td>229</td><td>209.2</td><td>214.4</td><td>203.3</td><td>206.2</td><td>209.7</td><td>219.4</td><td>225.8</td><td>226.3</td><td>180.0</td><td>176.9</td><td>186.3</td><td>191.9</td><td>179.1</td><td>195.5</td><td>179.6</td><td>179.6</td><td>189.9</td></tr>
<tr><td>Base ingredient 3 added (kg)</td><td>114.3</td><td>104.9</td><td>114.5</td><td>100.4</td><td>109.1</td><td>~~101.4~~</td><td>103.1</td><td>104.8</td><td>110.3</td><td>111.9</td><td>113.2</td><td>107.0</td><td>103.0</td><td>111.8</td><td>112.9</td><td>104.3</td><td>113.9</td><td>104.6</td><td>107.8</td><td>109.5</td></tr>
<tr><td>Base ingredient 4 added (kg)</td><td></td><td></td><td></td><td></td><td></td><td>101.8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mixing water temp. (°C)</td><td>13.2</td><td>14.1</td><td>13.8</td><td>14.1</td><td>13.7</td><td>13.9</td><td>13.8</td><td>14.0</td><td>14.1</td><td>14.0</td><td>14.1</td><td>13.9</td><td>14.2</td><td>13.8</td><td>14.3</td><td>13.9</td><td>14.2</td><td>13.8</td><td>14.4</td><td>14.3</td></tr>
<tr><td>Water added (kg)</td><td>656</td><td>615</td><td>671</td><td>607</td><td>628</td><td>582</td><td>598</td><td>602</td><td>630</td><td>647</td><td>656</td><td>646</td><td>622</td><td>675</td><td>695</td><td>630</td><td>702</td><td>638</td><td>651</td><td>661</td></tr>
<tr><td>Base Mixer No.</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td></tr>
<tr><td>Reaction time (min)</td><td>32</td><td>32</td><td>32</td><td>32</td><td>33</td><td>35</td><td>32</td><td>32</td><td>32</td><td>32</td><td>32</td><td>41</td><td>40</td><td>41</td><td>40</td><td>40</td><td>40</td><td>42</td><td>40</td><td>40</td></tr>
<tr><td>Reactor No.</td><td>1</td><td>2</td><td>2</td><td>1</td><td>1</td><td>2</td><td>2</td><td>1</td><td>1</td><td>2</td><td>2</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>Additives ingredients added (kg)</td><td>11.41 | 6.86 | 4.58</td><td>10.49 | 7.05 | 4.26</td><td>11.45 | 6.86 | 4.63</td><td>10.36 | 6.28 | 4.21</td><td>10.91 | 6.52 | 4.36</td><td>10.04 | 6.08 | 4.06</td><td>10.21 | 6.23 | 4.15</td><td>10.48 | 6.23 | 4.13</td><td>12.39 | 6.61 | 4.41</td><td>11.09 | 6.65 | 4.44</td><td>11.32 | 6.79 | 4.53</td><td>9.63 | 7.49</td><td>9.27 | 7.21</td><td>9.96 | 7.67</td><td>10.16 | 8.06</td><td>9.29 | 7.30</td><td>10.35 | 8.13</td><td>9.51 | 7.32</td><td>9.60 | 7.54</td><td>10.05 | 7.82</td></tr>
<tr><td>Additives mixer No.</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td></tr>
<tr><td>Moisture out (%)</td><td>50.0</td><td>49.3</td><td>52.7</td><td>49.3</td><td>50.5</td><td>50.0</td><td>52.2</td><td>49.3</td><td>52.8</td><td>54.0</td><td>49.4</td><td>51.9</td><td>53.8</td><td>53.1</td><td>53.1</td><td>51.3</td><td>52.5</td><td>52.5</td><td>55.5</td><td>53.8</td></tr>
<tr><td>QC batch sample number</td><td>776</td><td>778</td><td>780</td><td>782</td><td>784</td><td>786</td><td>790</td><td>792</td><td>794</td><td>796</td><td>798</td><td>800</td><td>803</td><td>806</td><td>809</td><td>812</td><td>815</td><td>818</td><td>821</td><td>824</td></tr>
<tr><td>Time start</td><td>00:11</td><td>00:35</td><td>01:28</td><td>01:47</td><td>02:45</td><td>02:57</td><td>04:01</td><td>04:16</td><td>05:17</td><td>05:38</td><td>06:32</td><td>09:03</td><td>09:32</td><td>10:10</td><td>10:42</td><td>11:07</td><td>11:38</td><td>12:09</td><td>12:45</td><td>13:06</td></tr>
<tr><td>Time end</td><td>01:35</td><td>01:48</td><td>02:40</td><td>02:55</td><td>03:47</td><td>04:12</td><td>05:15</td><td>05:28</td><td>06:21</td><td>06:43</td><td>08:01</td><td>09:42</td><td>10:07</td><td>10:38</td><td>11:06</td><td>11:26</td><td>11:58</td><td>12:48</td><td>13:12</td><td>13:31</td></tr>
<tr><td>Adjustments / Comments</td><td></td><td></td><td></td><td></td><td></td><td>Low milling speed. Milling time increased</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

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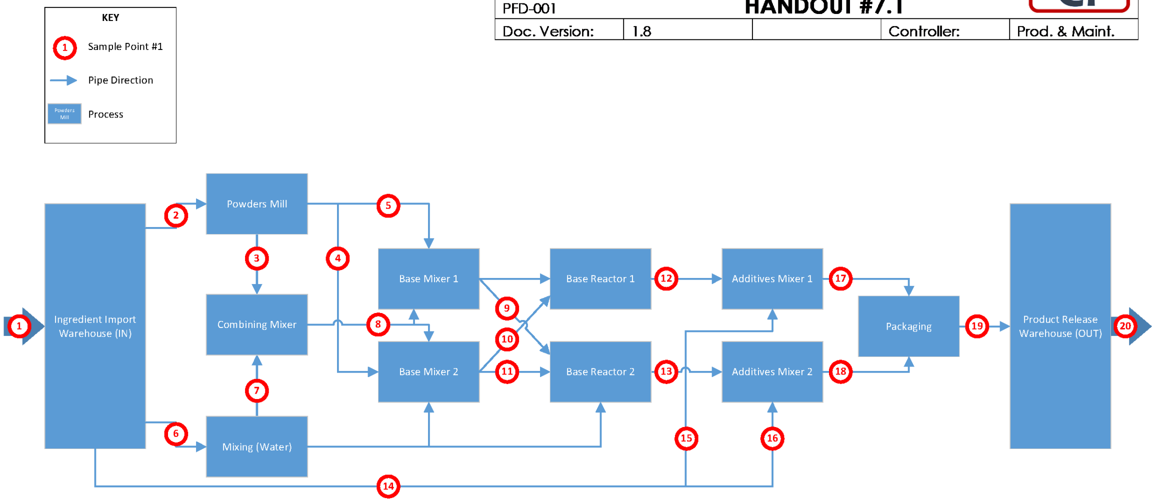
Measuring Industry Critical Abilities

SECTION 5

- **Handout #7.1 (PFD-001)**

PFD-001		HANDOUT #7.1	
Doc. Version:	1.8	Controller:	Prod. & Maint.



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Measuring Industry Critical Abilities

SECTION 6

- **Handout #5.1 (FOR-001)**
- **Handout #7.1 (PFD-001)**

FOR-001 (Product Formulation)	HANDOUT #5.1		Ci	
Doc. Version:	3.5		Controller:	Formulation

1. PURPOSE

1.1 This is the process to formulate Corporation Inc.'s flagship product.

1.2 NOTE: Changing the batch size (amount of product formulated) will have no effect on the duration and no effect on the equipment cost.

2. PROCESS OUTLINE

2.1 The formulating is a two-step process; (i) the base ingredients are combined, (ii) additive ingredients are added to make the final product.

3. MATERIALS REQUIRED

3.1 Required ingredients (1 can = 500g):

		Batch size:	
		500	grams
Raw Material Description	*Supplier*	*%w/w*	*Weight (g) (±1%)*
BASE INGREDIENTS (total: 490 g)			
Powder (P-1522)	Millings	10	50 ± 0.50
Powder (P-1601)	Millings	20	100 ± 1.00
Hydroxy-glycol (S-1135)	JJG	10	50 ± 0.50
Water	Mains MQ	58	290 ± 2.90
ADDITIVE INGREDIENTS (total: 10 g)			
Powder (LD-5528)	AOP Ltd.	1	5 ± 0.05
Powder (JT-7735)	Millings	0.6	3 ± 0.03
Sodium phenylbutyrate (S-1136)	Norotyne	0.4	2 ± 0.02
	Total:	100%	500g

3.2 Required ingredients have the following effects:

BASE INGEDIENTS

- Powder (P-1522) [main ingredient 1]
- Powder (P-1601) [main ingredient 2]
- Hydroxy-glycol (S-1135) [increases the stability of the product]
- Water [solvent; allows powders to react]

ADDITIVE INGREDIENTS

- Powder (LD-5528) [increase the brightness of product]
- Powder (JT-7735) [prevents reactions occurring in product]
- Sodium phenylbutyrate (S-1136) [adjusts the scent of product]

FOR-001 (Product Formulation)		HANDOUT #5.1		Ci
Doc. Version:	3.5		Controller:	Formulation

4. DURATION & COST

4.1 This process will take the following duration:

Preparation		Combining	
Bench: 30 min	Mixer: 30 min	Bench: 10 min	Mixer: 50 min

4.2 This test will cost:

- **Preparation step:**
  - Materials cost: $ 0.5 per gram of base made
  - Other costs: $ 200
- **Combining step:**
  - Materials cost: $ 36.75 per gram of additive used
  - Other costs: $ 50

5. REQUIRED EQUIPMENT BOOKING

5.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

6. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

30 min (Bench)

5.1 Weigh out P-1522 and P-1601 precisely.
5.2 Combine roughly in a 5 L stainless steel bowl.
5.3 Transfer these powders into the mixer.

30 min (Mixer

5.4 Slowly add water, while mixing at 60 rpm.
5.5 Continue mixing for an extra 10 minutes.
5.6 Add S-1135.

You may pause the process here

[COMBINING PHASE]

60 min (Bench & Mixer)

5.7 Sieve LD-5528 on to a glass plate.
5.8 Sieve JT-7735 on to a glass plate.
5.9 Slowly add LD-5528 and JT-7735 to mixer.
5.10 Add S-1136 slowly to the mixer.
5.11 Mix thoroughly for 45 minutes
5.12 Transfer mixture to can.

Authorised: HB Version Date: 01/10/2005

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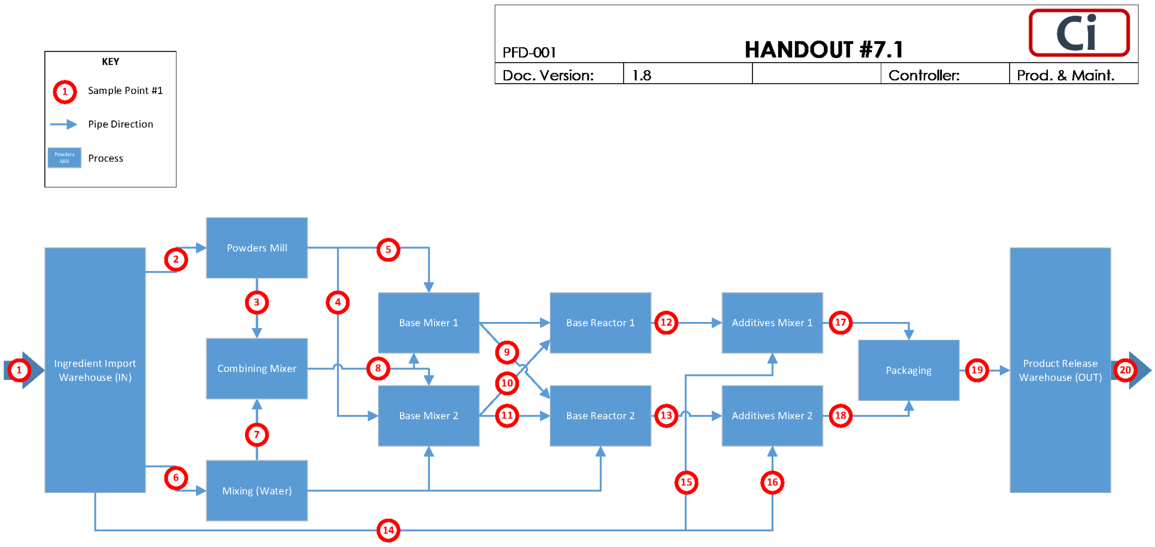
PFD-001
HANDOUT #7.1
Ci
Doc. Version:
1.8
Controller:
Prod. & Maint.
KEY
Sample Point #1
Pipe Direction
Process
Ingredient Import Warehouse (IN)
Powders Mill
Combining Mixer
Mixing (Water)
Base Mixer 1
Base Mixer 2
Base Reactor 1
Base Reactor 2
Additives Mixer 1
Additives Mixer 2
Packaging
Product Release Warehouse (OUT)

businessThink

Measuring Industry Critical Abilities

SECTION 7

- **Handouts #1.8 – 1.11 (MDS-005 – MDS-008)**
- **Handout #2.3 & #2.9 (TES-003 & TES-009)**
- **Handout #4.1 (MSS-001)**
- **Handout #8.1 (RES-001)**

MDS-007 (Exp.X2)	HANDOUT #1.10			Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

IDENTIFICATION			
▪ Internal Code	Exp.X2	▪ Supplier Product Name	
▪ Empirical Formula		▪ Data Sheet Prep. Date	26/07/2017
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]		▪ Partition K(C_8 / H) [unit]	
▪ Heat of Dissol. [kJ/kg]		▪ Toxicity (STEL) [g/kg.hr]	5.67E-09
▪ Melting Pt. [ºC]	1801	▪ Toxicity (LOEC) [g/kg.hr]	1.56E-11
▪ Solubility in Water [kg/L]		▪ Volatile Organics [%]	
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	
▪ Brightness (ISO) [%]		▪ Moisture [%]	3.92
▪ Roughness [µm]	138	▪ Conductivity [W/m.K]	5E-02
▪ Dust [mg/m³]	0.11	▪ Viscosity (max. sol.) [Pa.s]	
▪ Scott Bonding [J/m²]	6.84	▪ Density [g/dL]	202.4
▪ Odour		▪ Flammability in air [g/m³]	N/A
SAFETY			
▪ PPE Req.		▪ Storage Label	
SUPPLIER INFORMATION			
▪ Supplier Company Name		▪ Cost [$/t]	
▪ Supply History			

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: KW

Version Date: 26/07/2017

MDS-008 (Exp.X3)		**HANDOUT #1.11**		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

IDENTIFICATION			
▪ Internal Code	Exp.X3	▪ Supplier Product Name	
▪ Empirical Formula		▪ Data Sheet Prep. Date	26/07/2017
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]		▪ Partition K(C8|H) [unit]	
▪ Heat of Dissol. [kJ/kg]		▪ Toxicity (STEL) [g/kg.hr]	1.27E-08
▪ Melting Pt. [ºC]	1728	▪ Toxicity (LOEC) [g/kg.hr]	2.24E-12
▪ Solubility in Water [kg/L]		▪ Volatile Organics [%]	
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	
▪ Brightness (ISO) [%]		▪ Moisture [%]	6.06
▪ Roughness [µm]	105	▪ Conductivity [W/m.K]	3E-02
▪ Dust [mg/m³]	0.02	▪ Viscosity (max. sol.) [Pa.s]	
▪ Scott Bonding [J/m²]	6.22	▪ Density [g/dL]	203.1
▪ Odour		▪ Flammability in air [g/m³]	N/A
SAFETY			
▪ PPE Req.		▪ Storage Label	
SUPPLIER INFORMATION			
▪ Supplier Company Name		▪ Cost [$/t]	
▪ Supply History			

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: KW Version Date: 26/07/2017

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MDS-005 (Standard)		HANDOUT #1.8		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

IDENTIFICATION			
▪ Internal Code	Standard	▪ Supplier Product Name	
▪ Empirical Formula		▪ Data Sheet Prep. Date	26/07/2017
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]		▪ Partition K(C_8 | H) [unit]	
▪ Heat of Dissol. [kJ/kg]		▪ Toxicity (STEL) [g/kg.hr]	1.21E-08
▪ Melting Pt. [ºC]	1701	▪ Toxicity (LOEC) [g/kg.hr]	1.56E-11
▪ Solubility in Water [kg/L]		▪ Volatile Organics [%]	
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	
▪ Brightness (ISO) [%]		▪ Moisture [%]	6.21
▪ Roughness [µm]	125	▪ Conductivity [W/m.K]	2E-02
▪ Dust [mg/m³]	0.15	▪ Viscosity (max. sol.) [Pa.s]	
▪ Scott Bonding [J/m²]	7.05	▪ Density [g/dL]	208
▪ Odour		▪ Flammability in air [g/m³]	700
SAFETY			
▪ PPE Req.		▪ Storage Label	
SUPPLIER INFORMATION			
▪ Supplier Company Name		▪ Cost [$/t]	
▪ Supply History			

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

MDS-006 (Exp.X1)		HANDOUT #1.9		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

IDENTIFICATION			
▪ Internal Code	Exp.X1	▪ Supplier Product Name	
▪ Empirical Formula		▪ Data Sheet Prep. Date	26/07/2017
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]		▪ Partition K(C_8|H) [unit]	
▪ Heat of Dissol. [kJ/kg]		▪ Toxicity (STEL) [g/kg.hr]	1.26E-08
▪ Melting Pt. [ºC]	1765	▪ Toxicity (LOEC) [g/kg.hr]	3.23E-11
▪ Solubility in Water [kg/L]		▪ Volatile Organics [%]	
PHYSICAL PROPERTIES			
▪ Physical Form	POWDER	▪ Purity [%]	
▪ Brightness (ISO) [%]		▪ Moisture [%]	4.85
▪ Roughness [μm]	142	▪ Conductivity [W/m.K]	5E-02
▪ Dust [mg/m³]	0.28	▪ Viscosity (max. sol.) [Pa.s]	
▪ Scott Bonding [J/m²]	6.38	▪ Density [g/dL]	200.1
▪ Odour		▪ Flammability in air [g/m³]	600
SAFETY			
▪ PPE Req.		▪ Storage Label	
SUPPLIER INFORMATION			
▪ Supplier Company Name		▪ Cost [$/t]	
▪ Supply History			

Note: This Material Data Sheet should be read in conjunction with Material Specifications Sheet (MSS-001).

Authorised: KW Version Date: 26/07/2017

TES-003 (Drying Test)	HANDOUT #2.3		Ci	
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DRYING TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, LIQUID, SLURRY, EMULSION

1.3 Refer to the appropriate MDS to find the material's Physical Form.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Melting Point [ºC] / 0.0 / ± 0.1
- Purity [%] / 0.00 / ± 0.01
- Moisture [%] / 0.00 / ± 0.01

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (NONE)		Testing (**DRYING TEST**)	
Benches: 0 min	Equip: 0 min	Benches: 15 min	Ovens: 45 min

3.2 This test requires: 100 grams of material for the testing phase.

3.3 This test will cost:

- Preparation (NONE)
  - Materials cost: $ 0 per gram
  - Equipment cost: $ 0

- Testing (**DRYING TEST**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 100

4. REQUIRED EQUIPMENT BOOKING

4.1 This test requires the following specialised equipment:

- No specialised equipment required. No equipment needs to be booked.

TES-003 (Drying Test)		HANDOUT #2.3		Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

5.1 None

[TESTING PHASE]

15 min (Benches)

5.2 Weigh out 50.0 grams of the sample, precisely.

5.3 Place sample on to foil tray and spread evenly.

5.4 Weigh tray with sample and record initial weight.

45 min (Ovens)

5.5 Place tray in any available oven at 120ºC for 15 minutes.

5.6 While drying is occurring, clean preparation area thoroughly.

5.7 Remove tray and let sample return to room temperature.

5.8 Weigh dried sample with tray and record final weight. Calculate the moisture content as:

$$\frac{(m_f - m_i)}{100}$$

5.9 Repeat steps 5.2 and 5.3.

5.10 Calibrate the melting point apparatus before each test to ensure accurate readings.

5.11 Place tray in controlled oven, starting at 100ºC with heat gradient set at 2ºC/min. Press [START] to begin melting point test.

5.12 After 25 minutes, read melting point reading from front display.

5.13 While melting is occurring, clean area thoroughly and prepare for removal of sample(s).

5.14 Remove foil tray and dispose.

TES-009 (Dry Powder Test)	HANDOUT #2.9			Ci
Doc. Version:	1.0		Controller:	Qual. Contr.

1. PURPOSE

1.1 This is the process for the **DRY POWDER TEST**.

1.2 This test can be used only for the following material Physical Forms: POWDER, SLURRY

1.3 Refer to the appropriate MDS to find the material's Physical Form.

1.4 The FLOW DETECTOR undertakes eight (8) separate tests, using eight (8) separate detectors. Results for each test should be considered independently.

2. RESULTS REPORTED

2.1 This test provides the following results. The list below is formatted as:

Parameter / Precision (reported format) / Accuracy (error range).

- Toxicity (STEL) [g/kg.hr] / 0.00E-09 / ± 0.01 E-09
- Toxicity (LOEC) [g/kg.hr] / 0.00E-11 / ± 0.01E-11
- Brightness (ISO) [%] / 0 / ± 1
- Roughness [μm] / 0 / ± 5
- Dust [mg/m³] / 0.00 / ± 0.05
- Scott Bonding [J/m²] / 0.000 / ± 0.001
- Moisture [%] / 0.00 / ± 0.01
- Density [g/dL] / 0.00 / ± 0.01
- Flammability in Air [g/m³] / 0 / ± 10
- PPE Requirement

3. DURATION & COST

3.1 This test will take the following duration over two phases:

Preparation (**DRY** & **SIEVE**)			Testing (**DRY POWDER TEST**)	
Benches: 15 min	Ovens: 45 min	Sieve Rack: 60 min	Benches: 30 min	Flow Detector: 240 min

3.2 This test requires: 50 grams of material for the preparation phase which will also be used in the testing phase.

3.3 This test will cost:

- Preparation (**DRY**)
  - Materials cost: $ 2.5 per gram
  - Equipment cost: $ 200
- Preparation (**SIEVE**)
  - Materials cost: $ 7 per gram
  - Equipment cost: $ 400
- Testing (**DRY POWDER TEST**)
  - Materials cost: $ 35 per gram
  - Equipment cost: $ 750

4. REQUIRED EQUIPMENT

4.1 This test requires the following specialised equipment:

- Sieve Rack. Equipment must be booked.
- Flow Detector. Equipment must be booked.

TES-009 (Dry Powder Test)		**HANDOUT #2.9**		
Doc. Version:	1.0		Controller:	Qual. Contr.

5. PROCEDURE

Note: You may only pause this process where indicated. Otherwise you must continue.

[PREPARATION PHASE]

15 min (Benches)

5.1 Weigh out 50.0 grams of the sample, precisely.

5.2 Place sample on to two foil trays and spread evenly.

45 min (Ovens)

5.3 Preheat any available oven to 180ºC. Then place tray in oven.

5.4 *Must wait for 30 minutes.*

You may pause the process here

60 min (Sieve Rack)

5.5 Ensure that sieve meshes are clear from debris or residue.

5.6 Insert calibration powder into top sieve mesh. Close apparatus.

5.7 Run sieve rack by pressing [CALIBRATE].

5.8 Check meshes and remove powder.

5.9 Weigh out 100.0 grams of sample, precisely and insert into top sieve mesh.

5.10 Run sieve rack at 60 rpm.

5.11 *Must wait for 30 minutes.*

You may pause the process here

[TESTING PHASE]

30 min (Benches)

5.12 Transfer sieved sample to 2L glass container.

5.13 Slowly add deionised water while constantly stirring until no more dry powder can be seen.

210 min (Flow Detector)

5.14 Carefully transfer all of this into the top hopper of the flow detector.

5.15 Press [START].

5.16 *Must wait for 180 minutes.*

You may pause the process here

30 min (Flow Detector)

5.17 Note down all results from the front panel.

5.18 For any dust result greater than 0.01 mg/m^3, record the PPE requirement as "Gloves, Dust Mask"

5.19 Clean-up and shutdown machine.

6. SAFETY NOTES

6.1 Please familiarise yourself with the following safety notes:

- Specialised equipment with multiple tests conducted [1]
- Ensure appropriate training [2]
- Equipment will always give the result of NO HALFLIFE [3]

1. The Flow Detector contains eight (8) separate testing apparatus. The results of each test should be considered separately.
2. Please ensure that you are appropriately inducted and authorised to use this equipment.
3. This equipment is not suitable for use with radioactive material.

Authorised: PG Version Date: 15/08/2012

MSS-001	HANDOUT #4.1		Ci	
Doc. Version:	2.1		Controller:	Raw Ingred.

1. PURPOSE

1.1 This Material Specifications Sheet outlines the acceptable ranges (displayed as “x.xx – y.yy” OR “< x.xx” OR “> x.xx”) of chemical and physical properties.

1.2 Properties should be optimised by being at the HIGH, LOW, or MIDDLE of the acceptable ranges, where possible. Properties will have [HIGH], or [LOW], or [MID] to indicate range preference.

IDENTIFICATION			
▪ Internal Code		▪ Supplier Product Name	
▪ Empirical Formula		▪ Data Sheet Prep. Date	
CHEMICAL PROPERTIES			
▪ pH (max. sol.) [unit]	6.5 – 7.5 [MID]	▪ Partition K(C_8 | H) [unit]	15 – 20 [LOW]
▪ Heat of Dissol. [kJ/kg]	0.300 – 0.400 [LOW]	▪ Toxicity (STEL) [g/kg.hr]	< 1.50E-08 [LOW]
▪ Melting Pt. [ºC]	1750 – 1850 [HIGH]	▪ Toxicity (LOEC) [g/kg.hr]	< 5.00E-11 [LOW]
▪ Solubility in Water [kg/L]	< 5 [LOW]	▪ Volatile Organics [%]	< 10 [LOW]
PHYSICAL PROPERTIES			
▪ Physical Form		▪ Purity [%]	> 92.5 [HIGH]
▪ Brightness (ISO) [%]	> 90 [HIGH]	▪ Moisture [%]	< 5.00 [LOW]
▪ Roughness [µm]	> 100 [HIGH]	▪ Conductivity [W/m.K]	< 0.005 [LOW]
▪ Dust [mg/m³]	< 0.30 [LOW]	▪ Viscosity (max. sol.) [Pa.s]	0.85 – 1.00 [LOW]
▪ Scott Bonding [J/m²]	6.00 – 7.00 [LOW]	▪ Density [g/dL]	205 – 215 [HIGH]
▪ Odour	NONE or LOW	▪ Flammability in air [g/m³]	< 1500 [LOW]
SAFETY			
▪ PPE Req.		▪ Storage Label	
SUPPLIER INFORMATION			
▪ Supplier Company Name		▪ Cost [$/t]	
▪ Supply History			

Authorised: JW

Version Date: 19/10/2012

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RES-001 **HANDOUT #8.1**

Date: 25/07/2017

Dear Sir/Madam,

Please find below the results from your requested tests. As always, you are encouraged to verify results where possible before use. Additionally we have extended TES-003 once only so to include conductivity results. This is not standard procedure and does incur extra charge, as discussed.

Test Procedure: TES-003

Sample Number	Sample Name	Melting Point [°C]	Moisture Content [%]		ADDITIONAL TEST RESULT:	Conductivity [W/m.K]	End Time	Lab Tech.
1	Exp.X1	1765	4.85			0.05	09:55	KW
2	Exp.X2	1801	3.92			0.05	10:18	JG
3	Exp.X3	1728	6.08			0.03	13:10	MS
4	Standard	1701	6.21			0.02	14:08	KW

Test Procedure: TES-009 (NOTE: The FLOW DETECTOR undertakes eight (8) separate tests, using eight (8) separate detectors. Results for each test should be considered independently.)

Sample Number	Sample Name	Roughness [μm]	Dust [mg/m3]	Flammability [g/m3]	Scott Bonding [J/m2]	Density [g/dL]	End Time	Lab Tech.
1	Exp.X1	138	0.28	0600	6.38	200.12	11:01	FJ
2	Exp.X2	142	0.11	N/A	6.84	202.40	12:17	MS
3	Exp.X3	105	0.02	N/A	6.22	203.09	15:42	JG
4	Standard	125	0.15	0700	7.05	206.97	16:23	AO

Sample Number	Sample Name	Tox. (STEL) [g/kg.hr]	Tox. (LOEC) [g/kg.hr]	Density (*not collected*)			End Time	Lab Tech.
1	Exp.X1	1.26E-08	3.23E-11				11:01	FJ
2	Exp.X2	5.67E-09	2.04E-11				12:17	MS
3	Exp.X3	1.27E-08	2.24E-12				15:42	JG
4	Standard	1.21E-08	1.56E-11				16:23	AO

The Quality Control Department makes no representations as to the quality or veracity of these results.

***** Please do not reply to this email as it has been sent from an unattended mailbox. *****