Appendix I

Definitions of critical thinking

There are several definitions of critical thinking available in the literature consulted. Gosnell (2010) indicates that Facione's (1990) definition is commonly referred to and regarded as most popular quoted general definition of critical thinking as it was confirmed by means of a Delphi study:

> *'The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the circumstances of inquiry permit.*'

The short version of this definition is: 'the process of purposeful, self-regulatory judgement (Facione in Gosnell 2009).

Ennis (1985 & 2009) is regarded as the author who sparked interest on the critical thinking topic in 1962. Ennis (1985 & 2009) classified critical thinking as an activity, a quality, and a skill. Panettieni (2015) also mentioned that critical thinking falls both in the cognitive and affective domains. Sternberg's (n.a.) view is that critical thinking is made up of mental processes, strategies, and used to solve problems, decision making and to learn new concepts. In my opinion, to be a critical thinker, you must be able to use your head, your heart and your hands.

Adler and Carlton (2007) (in Gosnell 2010) mention that critical thinking in the radiography context must be based on professional knowledge and experience. To make a judgement, values such as ethical standards and integrity must be considered in the best interest of the patient, for optimal patient-centred care and improved patient outcomes. For this reason, Jackson, Iganvaticius and Case (2006) (in Gosnell 2010) indicate that clinical judgment is the discipline-specific approach to critical thinking. Herrmann and Arnold (2016) combine critical thinking and problem solving and indicate four steps to attain critical thinking, namely: to identify the problem; investigate the problem; formulate possible responses/viable solutions and lastly select the best solution.

The cognitive skills identified are interpret, analyse, evaluate, infer, explain and self-regulate. In the affective domain, a practitioner must be inquisitive, open-minded, systematic, analytic, truth-seeking, self-confident and mature.

The following definitions of critical thinking are related to the radiography context:

Ennis (1985 & 2009) defines the concept as: 'Critical thinking is reflective and reasonable thinking that is focused on deciding what to believe or do'. Ennis (1985) classifies critical thinking as a practical activity; a disposition and a skill.

Sternberg's (n.a.) definition is: 'Critical thinking comprises the mental processes, strategies and representations people use to solve problems, make decisions and learn new concepts'.

Herrmann and Arnold (2016) 'critical thinking is a reflective decision-making process that is necessary because every patient presents a new situation or challenge.' When the action is performed based on theory (professional knowledge) and experience it is regarded as critical thinking. This must be accompanied by professional judgement, ethical standards and integrity. These authors regard analyses, evaluation, critique and create as the elements of critical thinking.

Scriven and Paul (1996). 'Critical thinking is, very simply stated, the ability to analyse and evaluate information'.

The working definition to support critical thinking and the taxonomy in this project is:

A self-regulated radiographer/radiography student must apply professional knowledge (cognitive domain), clinical experience (skills) and ethical standards (affective domain) to interpret, analyse, evaluate, explain and judge concepts and information for improved patient-centred care and outcomes.

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Appendix II

The critical thinking taxonomy framework for radiography

- Beyer (1988) proposed a framework for thinking skills on five levels. On level one is information processing, level two has problem solving, involving the lower levels on Blooms taxonomy and a four-step problem solving method. On level three he presents critical thinking. This links to the questioning of factual accuracy and credibility of information or a source. On level four information processing is depicted with the action verbs analyse, evaluate and create. This links to levels four to six of the Blooms taxonomy. The last level, level five entails decision-making strategies, to identify options, evaluate and choose the best. Levels three to five were used in the taxonomy.
- The SOLO (Biggs n.a) presents five levels of understanding. At the higher levels are multistructural (indicates competence), the relational and extended abstract levels (agree with the higher cognitive levels on the Bloom's taxonomy).
- Imrie (1995) indicates that for critical thinking, principles (knowledge), skills (competence) and creativity (non-routine methods) are required to solve problems. This author adapted the Bloom's taxonomy and proposed the 'RECAP taxonomy' with tier one referring to recall, comprehension and application and tier two problem solving skills – analyse, evaluate and create.
- The most often referred to taxonomy is that of Bloom (1956). This taxonomy was revised (Krathwohl 2002) and now includes the knowledge (noun) dimension with four categories and the cognitive (verb) dimension with six categories. With this revision, learning objectives are represented in two dimensions to include metacognition and self-regulated learning in the affective domain.
- Gamble (2009) refers to applied competence at three levels, namely practical (the ability to perform), foundational (understand what to do and why), and reflexive competence (integrate and connect, learn from actions and adapt to changes and unfamiliar circumstances). This author also presents the cognitive demand on three levels, namely the factual recall (simple and medium), understanding of principles (simple, medium and challenging) and lastly problem solving (simple, medium and challenging).
- Miller's (1990) pyramid is applicable to clinical competence. It depicts knowledge (knows) in the base of the pyramid), followed by competence (knows how), performance (shows) and action (does) in the apex.

- The taxonomy presented by Krathwohl et al (1964) is applicable to the affective domain and metacognition. The action verbs value, organise and characterise are linked to this level.

In Table 1, the above information was summarised and linked to the working definition of critical thinking (Appendix I):and mapped in a taxonomy adapted from Potter and Kustra (2012)

> *A self-regulated radiographer/radiography student must apply professional knowledge[1], clinical experience[2] and ethical standards[3] to interpret, analyse, evaluate, explain and judge concepts and information for improved patient-centred care and outcomes.*

Table 1 Taxonomy framework for critical thinking (adapted from Potter and Kustra 2012)

1 Cognitive domain					2 Clinical skills	3 Meta-cognition	4 TLA Activities
Beyer 1988	**SOLO Biggs n.a.**	**Revised Bloom Knowledge dimension Krathwohl 2002**	**Revised Bloom Cognitive dimension Krathwohl 2002**	**Gamble 2009**	**Miller 1990**	**Krathwohl et al 1964**	
Critical thinking Information processing Analyse Evaluate Create	**Relational** Students learn to integrate several different aspects into a structure	**Procedural knowledge** Subject specific skills Subject specific methods and techniques Criteria to decide on procedures	Analyse Evaluate	**Understanding of principles** Simple Medium Challenging	Knowledge (knows) Compe-tence (knows how)	• **Value** Justify Respect Persuade Believe	• Case studies, simulations • Concept maps • Research projects • Reflective journals • Student seminars and debates • Problem-Based Learning and Inquiry Learning
Decision-making	**Extended Abstract** Students can generalise what they learn into a new area of knowledge	**Meta-cognitive Knowledge** Strategic knowledge Contextual and conditional knowledge Self-knowledge	Create	**Problem solving** Simple Medium Challenging	Perfor-mance (shows) Action (does)	• **Organise** Examine Clarify Create Integrate • **Charac-terise** Internalise Review Conclude Resolve Judge	• Self-directed projects • application, argumentation, evaluation • Case studies • reflection, argumentation, evaluation, forecasting • Develop a theory or model • Problem Based Learning and Inquiry learning • Teaching

In Table 2 the taxonomy framework for radiography is presented. The different colours depict the three domains: the cognitive domain[1] (yellow, refers to intellect); competence domain[2] (green, refers to creativity, safety, growth and practical) and the meta-cognitive domain[3] (indigo, refers to professionalism, trust and wisdom). In the last column, the teaching and assessment activities are presented.

Important principles are to integrate critical thinking in the curriculum and to apply constructive alignment to scaffold critical thinking. A programme approach is necessary. Use the taxonomy framework (Table 2) to benchmark the teaching, learning and assessment activities. Table 3 captures the skills developed through critical thinking.

Table 2 Taxonomy framework for critical thinking in radiography

	1 Cognitive domain	2 Clinical skills	3 Metacognition	4 TLA activities
Relational level 3	**Procedural knowledge** • Subject specific skills • Subject specific methods • Subject specific techniques • Criteria to decide on procedures **Process information:** • Analyse • Evaluate • Integrate several different aspects into a structure **Understand principles** • Medium & challenging levels	**Perform (shows how)**	**Metacognitive knowledge** • Strategic knowledge • Contextual and conditional knowledge • Self-knowledge • Self-awareness	• Case studies • Simulation • Role play • Concept maps • Research project • Reflective journal • Student seminars and debates • Socratic questioning • Problem-based learning and Inquiry learning • Work-place learning
Extended abstract level 4	**Extended Abstract** • Students can generalise what they learn into a new area of knowledge **Process information:** • Create • Decision-making **Solve problems** • Medium & Challenging levels	**Action (does)**	**Value** • Justify • Respect • Persuade • Believe **Organise** • Examine • Clarify • Create • Integrate **Characterise** • Internalise • Review • Conclude • Resolve • Judge	• Self-directed projects • Application of principles • Argumentation • Evaluation • Case studies • Reflection • Reflective practice • Reflection-in-action • Debriefing • Forecasting • Develop a theory or model • Problem Based Learning and Inquiry learning • Work-place learning • Teaching
Colour key	**Yellow – cognitive, intellect**	**Green – creativity, growth, safety, practical**	**Blue – professionalism, trust, wisdom**	**TLA = Teaching, learning and assessment activities**

Table 3 Skills and values developed through critical thinking (Adapted from Castle 2009)

Component	**Explanation**	**Example**
Skills		
Process information	Inquisitively seek knowledge, truth and understanding Identify and search relevant source for evidence, facts or knowledge and gather data	Topic related literature search Evidence-based learning
Knowledge transfer	Change from one concept to another	Radiation safety principles
Analyse	Break a whole into parts to discover components, function and relationships Value focussed, systematic and comprehensive approaches to issues	X-ray tube design and operation
Evaluate	Read the evidence and clarify issues Make judgements and draw conclusions based on evidence	Journal article
Reflect	Contemplate own thinking and assumptions to allow for a deeper understanding	Reflective diary in clinical practice Imaging protocols
Create	Generate, discover or re-structure ideas and propose alternatives	Perform a SWOT analysis
Classify (Make decisions)	Identify inconsistencies Distinguish relevant from irrelevant Recognise differences and similarities	Compare journal articles on the same topic
Problem solving	Predict/anticipate potential outcomes and consequences	Clinical case studies
Values		
Put into context	Consider the background and influences relevant to an issue	Health inequalities
Persevere	Pursue a module to overcome barriers	Research project Oral presentations
Flexible	Adapt, modify or change ideas and behaviours	Clinical assessments
Open-minded	Accommodate divergent views Identify own bias/prejudice	Imaging technologies
Confidence	Develop effective communication style and reasoning skills	Communication skills Image interpretation skills

Where to start implementing critical thinking and using the taxonomy framework:

- Critical thinking is associated with curriculum integration. Decide which aspects of critical thinking you need to focus on in the programme.
- Identify one aspect of critical thinking to teach and assess.
- Use assignments and clinical case studies for this purpose.

The five-step model to facilitate critical thinking (Duron et al 2006)

1. determine the learning outcomes with the relevant action verbs.
2. teaching takes place through questioning.
3. practice through active learning
4. review, refine, improve by monitoring class activities and obtaining feedback from students while they learn to monitor their own learning.
5. provide feedback and assessment of learning.

The cycle continues by implementing step one again.

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Appendix III
A summary of the process and literature to compile the taxonomy framework in radiography

A qualitative review and analysis of relevant literature was used to compile a taxonomy framework for critical thinking. Denscombe (2007) supports the analysis of literature because of the availability in the public domain (Denscombe 2007). An in-depth investigation of the specific literature was used to address the questions and propose a taxonomy framework (Hammarberg, Kirkman & De Lacey 2016).

A literature search was done using various search engines and the key words for the search were: critical thinking in radiography'; 'taxonomies'; 'taxonomy for critical thinking'. Purposive sampling was then used to select relevant resources. Thereafter content analysis of the selected documents was done to extract the information guided by the questions (Hammarberg et al 2016). Denscombe (2007) warns that documents should not be accepted at face value without a critical analysis of the authenticity, credibility and trustworthiness of the material.

Credibility and Trustworthiness

To confirm trustworthiness, the researcher verified the credibility, transferability, confirmability, dependability, validity and reliability of the taxonomy framework (Cresswell 2009). To ensure credibility, triangulation was applied. This means that more than one resource was used to confirm the same information. To address transferability, the researcher asked the question if the findings are transferable to other contexts. To exclude researcher bias and increase transparency, the evidence collected is displayed as an audit trail which addressed the confirmability. In addition, the researcher provided the guidelines and steps followed to address the question 'how repeatable is the study' and confirm dependability (Cresswell 2009).

Process

In this section the outcomes of the search for information is provided to indicate the selection of resources used to answer the questions (Figure 1 and Appendix I). The literature search yielded twenty-nine resources dated between 1964 and 2016, of which eight were excluded. Four questions guided the information search and presentation if the information. Although some authors question if critical thinking can be taught and

assess, others propose a variety of student-centred teaching and assessment methods to encourage metacognition and reflection-in-action.

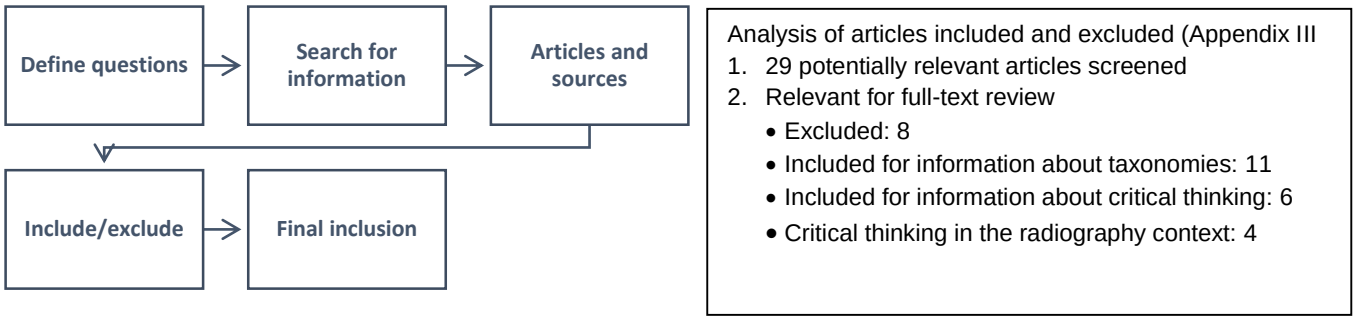

Figure 1 Flowchart of inclusion and exclusion of resources

The quality and credibility of the resources identified

The literature resources identified date between 1964 and 2016. Two resources are dated 2016, one from 2015 and one from 2012. This situation indicates a gap in the available published information on this topic. Two of the resources are doctoral studies completed at universities in the US. The affiliations of the authors of the articles indicate that they are authorities on the topic. This supports the quality of the information used to complete the project.

Source	Kind of resource	Concepts for critical thinking	Teaching methods for critical thinking and problem solving
Stadt R, Ruhland S 1995 Critical Thinking abilities of radiologic technology students	Abstract only Search for article		
1Miller GE. 1990. The assessment of clinical skills/competence/performance. Acad Med 65(9): s63-s67. skills/competence/performance	Taxonomy for competence		
2Krathwohl DR. 2002. A Revision of Bloom's Taxonomy: An Overview, Theory Into Practice, 41:4, 212-218, DOI: 10.1207/s15430421tip4104_2. Accessed on 6 February 2018.	Article Taxonomy	2-D framework (Taxonomy table) Knowledge levels – noun – subject matter (facts, concepts, procedures and metacognition)	

		Cognitive levels = verb (remember, understand, apply, analyse, evaluate and create Classify goals, objectives, standards, activities, assessment to provide an overview of the unit/module/assessment Check alignment, missed opportunities, and guide improvements		

Source	**Kind of resource**	**Concepts for critical thinking**	**Teaching methods for critical thinking and problem solving**
Athanssiou N, Jeanne M, McNett CH 2003. Critical thinking in the management classroom: Bloom's taxonomy as a learning tool. Journal of Management Education Vol 27 Issue 5	(no full text)		
Duan Y 2006 Selecting and applying taxonomies for learning outcomes: A nursing perspective. Int Journal of nursing education scholarship (no full text)	(no full text)		
3Biggs JB. n.d. Bigg's structure of observed learning outcome (SOLO) taxonomy. Teaching and Educational Development Institute, University of Queensland.	Structure of Learning Outcome (SOLO) taxonomy first compiled by Biggs and Collis 1982 Ass		
4Gamble J. 2009 The relation between knowledge and practice in curriculum and assessment University of Cape Town (This paper is a revised version of a concept paper prepared for Umalusi in 2009. https://www.umalusi.org.za/docs/research/2009/jgamble.pdf	Taxonomy + types of knowledge		
5Potter MK and Kustra E. 2012. A primer on learning outcomes and the SOLO taxonomy. Course design for constructive alignment. Centre for Teaching and Learning University of Windsor. http://www1.uwindsor.ca/ctl/system/files/PRIMER-on-Learning-Outcomes.pdf.	Taxonomy		

Source	Kind of resource	Concepts for critical thinking	Teaching methods for critical thinking and problem solving
Tracy Herrmann, MEd, RT(R) and Angie Arnold, MEd, RT(R) Critical-Thinking and Problem-Solving Strategies Chapter 4. Radiology Key available from Radiology Key available from https://radiologykey.com/critical-thinking-and-problem-solving-strategies/	Chapter *	Provides definition of critical thinking Reasons why needed in radiography 4 step process for critical thinking	
Susan Gosnell 2010* Teaching And Assessing Critical Thinking In Radiologic Technology Students *D Ed dissertation University of Central Florida (EXTENSIVELY USED)*	D Ed dissertation	Definitions in general and for health sciences Most vital skill and necessary to: Improve patient care outcomes, use for reasoning, problem solving, critical thinking and clinical judgement Provide related concepts	Methods proposed
C. S_a dos Reis a, b, *, J.A. Pires-Jorge c, H. York d, L. Flaction c, S. Johansen e, f, S. Maehle Curricula, attributes and clinical experiences of radiography programs in four European educational institutions	Not used		
JosephCastillo[a]CarmelJ.Caruana[b]DavidWainwright[a]* The changing concept of competence and categorisation of learning outcomes in Europe: Implications for the design of higher education radiography curricula at the European level Author links open overlay panel	Not used		

Source	Kind of resource	Concepts for critical thinking	Teaching methods for critical thinking and problem solving
Duron R, Limbach B, Waugh, W. 2006. Critical Thinking Framework For Any Discipline. International Journal of Teaching and Learning in Higher Education. Vol 17, No 2, 160 to 166. www.ijtlhe	Blooms Critical thinking = analyse, evaluate information and creates Description aligns critical thinking with the action verbs	Critical thinking framework – 5 step framework for critical thinking + Definition Steps: 1. Identify outcomes 2. Teach through questioning 3. Practice – promote and utilise active learning	Active teaching essential

		4. Review, refine and improve 5. Feedback and assessment of learning 6. 7. Challenges = class size + time frames Definitions: Norris 1985 Elder and Paul 1994 Harris and Hodges 1995	

Source	**Kind of resource**	**Concepts for critical thinking**	**Teaching methods for critical thinking and problem solving**
6Imrie BW. 1995 Assessment for Learning: quality and taxonomies, Assessment & Evaluation in Higher Education, 20:2, 175-189, DOI: 10.1080/02602939508565719 **To link to this article: https://doi.org/10.1080/02602939508565719**	Article Different taxonomies introduced for the domains: cognitive (Bloom), psychomotor (Simson 1966), affective (Krahtwohl 1964) Problem solving made up of analyse, evaluate and create = deep learning	Critical thinking and problem solving – use principles, skills, creativity to solve use non-routine methods Cognitive – analyse, etc. Psychomotor – performance of skills Affective: respond, organise, conceptualise Example of aligning knowledge and skill in a table with action verb and a table showing tier 1 and tier 2 in the RECAP model by Imrie 1984– Tier 2 – analyse, evaluate, create Crooks 1988b has three categories – Recall, comprehension, critical thinking and problem solving (p179) SOLO taxonomy – NB table p 183 and p 185 (SOLO taxonomy)	

Source	**Kind of resource**	**Concepts for critical thinking**	**Teaching methods for critical thinking**

			and problem solving
Ennis RH 1985. A logical basis for measuring critic**al** thinking skills Educational Leadership p 44 to 48	Article	Define critical thinking 'Critical thinking is reflective and reasonable thinking that is focused on deciding what to believe or do' p45 = practical activity – you decide what to do therefore has disposition and skill (ability) needed Helpful scheme to illustrate the deciding process (p47)	
Ennis RH 2009 (or 1985?) Critical thinking assessment. Theory into practice vol 32 issue 3	Article	Define critical thinking = decide what to do, decide what to believe to do Disposition = open minded, pay attention to situation, seek reasons Critical thinking – seek clarity, inference, decision making (critical thinking), problem solving	

Source	**Kind of resource**	**Concepts for critical thinking**	**Teaching methods for critical thinking and problem solving**
R. Higgins*, P. Hogg b, L. Robinson Constructive alignment of a research-informed teaching activity within an undergraduate diagnostic radiography curriculum: A reflection			
Sternberg, Robert J. n.a. Critical Thinking: Its Mature, Measurement, and Improvement. National Inst. of Education (ED), Washington, DC.PUB DATE [86]NOTE37p.PUB TYPE Viewpoints (120)-- Information Analyses (070)	Article ? chapter	Definition (page 3) Critical thinking comprises the mental processes, strategies, and representations people use to solve problems, make decisions and learn new concepts	
Nancy E. Adams, MLIS Bloom's taxonomy of cognitive learning objectives	Article describe Blooms in general		

See end of article for author's affiliation. DOI: http://dx.doi.org/10.3163/1536-5050.103.3.010	Not used		
Pieterse, T., Lawrence, H. & Friedrich-Nel, H. 2016. Critical thinking ability of 3rd year radiography students. *Health SA Gesondheid* 21(1):381-390.*	Components of critical thinking: Analyse Problem solving Justify Evaluate create		

Source	**Kind of resource**	**Concepts for critical thinking**	**Teaching methods for critical thinking and problem solving**
7Amer A 2006. Reflections of Bloom's revised taxonomy Electronic Journal of research in Educational Psychology. No 8, Vol 4 (1) p 213 to 230 (Art_8_94	History of Bloom's taxonomy, weaknesses, reasons for the revision, = approaches to create student centred approach e.g. constructivism, metacognition (added), self-regulated learning Self-awareness, self-monitoring, self-evaluation are crucial, metacognition central to SRL 2 dimensions of Bloom analysed. More complex cognitive processes – analyse, evaluate, create		Application of the revised taxonomy – analyse teaching
8Armstrong P Blooms taxonomy for teaching, learning and assessment	Article Lorin Anderson – added relevance for 21st century student	Link to article = Bloom's taxonomy	

Source	**Kind of resource**	**Concepts for critical thinking**	**Teaching methods for critical thinking**

			and problem solving
Wilson K. 2016. Critical reading, critical thinking: Delicate scaffolding in English for academic purposes (EAP). Thinking skills and creativity 22 256 - 265	Framework for critical thinking by Davies and Barnett (2015)	Article more about critical reading than critical thinking	
9Forehand M n.d. Bloom's Taxonomy From the book: Emerging Perspectives on Learning, Teaching and Technology p1 – 10 (Independent chapter review)	Shows the history of Bloom and the origin of higher and lower order thinking		
Ruth M. Hackworth, 2009 Radiation Science Educators' Perception of Obstacles in the Use of Critical Thinking PhD Thesis Ohio state university	PhD		Class discussions Obstacles mentioned
Panettieni RC 2015 Can critical thinking skills be taught? Radiologic Technology Vol 86 no 6 p 686	Article		Adjust practice to unique situation, close the gap between theory ad practice
10Krathwohl, D.R., Bloom,B.S. and Masia, B. B. (1964).*Taxonomy of educational objectives, Book II. Affective domain.* New York, NY. David McKay Company, Inc. https://thesecondprinciple.com/instructional-design/threedomainsoflearning/	Article on taxonomy		
Castle A. 2009. Defining and assessing critical thinking skills for student radiographers. Radiography. 15:70 – 76.	Article		Applicable
11Beyer BK. 1988. Developing a scope and sequence for thinking skills instruction. Educational Leadership p26-30	Article		

Colour codes:

Xxxxx Did not use the article/resource in the project 8

Xxxxx Used the article/resource in the project for information on taxonomies 11

Xxxxx Used the article/resource in the project for information on critical thinking 6

Xxxxx Used the article/resource in the project for information on radiography 4