Conceptualising the Knower for a New Engineering Technology Curriculum

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Engineering technology education in South Africa has undergone a number of significant alterations in the past three decades. The most recent of these is the establishment of a new degree qualification – Bachelor of Engineering Technology – to replace the qualification for engineering technologists and decouple it from the existing engineering technician qualification. However, the new qualification standards alone do not give a clear distinction between knowers in the engineering technician and engineering technologist categories. This lack of clarity about what knower the new programme is intended to produce is a stumbling block to educators who need to plan, develop and implement the new curriculum. It is only through understanding the knower who should be developed that questions pertaining to what kinds of knowledge should be encountered and the encounters themselves can be answered. In this paper, the intended knower dispositions is conceptualised for the new programme by carrying out a comparative analysis of the current and new exit-level outcomes. Bloom’s taxonomy and Luckett’s knowledge plane are used as lenses to perform the analysis and draw a distinction between knowers in the engineering technician and engineering technologist categories. The analysis suggests that the engineering technologist category exhibits a relative shift towards subjective and theoretical “ways of knowing”. How this shift could influence the new curriculum particularly with regard to developing effective scaffolding for engineering technology students is also fleshed out.

Keywords: Engineering technology education; curriculum development; exit-level outcomes; knower conceptualisation

Introduction

In South Africa, engineering technology education has undergone many transformations over the years with the most recent being a paradigm shift in intended graduate outcomes. Some examples of these past transformations are presented in Civil Engineering Contractor (1993) which expose conflicting opinions on the government's decision to have technikons offering degree programs. In 2005, all technikons changed to universities of technology in response to the demand for research and postgraduate programmes in the country (Christiansen and Baijnath, 2007).

The most recent of these transformations is the establishment of a new degree qualification to enable alignment of engineering technology qualifications and their compliance with the Higher Education Qualification Framework (HEQF). The new degree programme - Bachelor of Engineering Technology (BEngTech) - is intended to replace the current qualification format for engineering technologists comprising the National Diploma in Engineering Technology (NDipEng) and Bachelor of Technology: Engineering (BTech). The BEngTech qualification is a dedicated three year bachelors degree and is unlike any of the past or present engineering technology programmes offered by Universities of Technology and Comprehensive Universities in South Africa. Moreover, there are dedicated exit-level outcomes, newly developed by the Engineering Council of South Africa (ECSA), for this qualification. These outcomes are intended to decouple the BEngTech from the existing engineering technician qualification. Educators involved in the development of the new curriculum have the task of planning, developing and implementing a programme so that the intended decoupling is realised and the sought-after knower dispositions for engineering technologists are successfully accounted for. The potential risk is that a lack of clarity on the part of curriculum developers as to what sort of graduate should be developed could lead to superficial alterations of the old programme and even reproduction of it. Therefore, there is a need to extract the knower that the new program intends to develop from the available information.

This paper deals with conceptualising the knower that this new programme intends to develop. A comparative analysis of the exit-level outcomes and knowledge areas stipulated in ECSA standards for the technician and technologist qualifications is carried out. The analysis is performed using Bloom's taxonomy (Anderson et al, 2001) and Luckett's ways of knowing plane (Luckett, 2001) which help to conceptualise the relative shift in the complexity of the educational goals and ways of knowing in the two programmes. In addition, implications of this shift for the design of the new curriculum are also fleshed out. Specific attention is given to implications for the development of scaffolding as it is argued in this paper that the knowledge construction process is at the centre of this paradigm shift in technology education.

Problem, Purpose and Approach

In South Africa, there is a need for education and registration models for engineers, engineering technologists and engineering technicians that conforms to their distinct roles in practice (Engineering Profession Act of 2000). Previously, the educational articulation model for engineering technologists initially followed the same route as engineering technicians – i.e. NDipEng, after which students entered the BTech(Eng) programme to obtain a degree qualification. ECSA identified (ECSA-HEQF, 2009) that this format was not in compliance with the newly promulgated HEQF and that a new degree qualification should be created for engineering technologists which would be completely decoupled from the engineering technician qualification. The BEngTech qualification has been created for this purpose with a set of newly developed exit-level outcomes to guide it.

The problem lies in enacting this intended decoupling in the curriculum. Since the inception of the engineering technologist programme, its educational goals have been the same as that of an engineering technician up to the point of completion of the NDipEng. The new programme must now be decoupled from the engineering technician programme and should develop a graduate who is a distinct engineering technologist. In order to develop a curriculum that can achieve this, that distinction must be precisely known.

In engineering technology, as with most professionally-oriented curricula, there is a proclivity for developing curricula around outcomes. Shay (2013) and Allais et al (2009) even suggest that knowledge differentiation discourse in professionally-oriented curricula has been subordinated to outcomes. An international framework has been put in place to align the focus of university engineering programmes towards “competence development and the achievement of so-called intended, expected or desired learning outcomes of the learning process” (OECD, 2009). Exit-level outcomes are adopted as the main evaluation “criteria” for professional engineering academic degrees by the accreditation body ECSA in line with the Washington Accord (IEA, 2016). The curriculum practice and development approach in engineering in higher education is outcomes-based. However, the outcomes alone – as will be shown in this paper – provide an ostensible distinction between knowers in the engineering technician and engineering technologist categories.

Bearing in mind that the current institutional and international curriculum practice with regards to engineering education and the aforementioned proclivity towards outcomes, the selected approach is to the frame the problem in the context of outcomes. The approach taken here is to analyse the new engineering technologist outcomes in relation to the engineering technician outcomes to elucidate the distinction between them and extricate the knower to be developed. The knowledge areas stipulated by the qualification standards are used in conjunction with the outcomes for this purpose. Bloom's taxonomy (Anderson et al, 2001) and Luckett's ways of knowing (Luckett, 2001) are employed to ground the analysis in terms of assessing the difference between the cognitive demands and 'ways of knowing' for each category of graduate.

In addition to extricating the intended knower, the analysis is extended by interrogating the knowledge construction and scaffolding implications to inform curriculum development and implementation. Simply put, the knower to be developed must inform curriculum development. For instance, there is an inherently higher standard of intended graduate attributes/exit-level outcomes associated with the new programme. The South African Qualifications Authority (SAQA) uses the National Qualifications Framework (NQF) to distinguish different levels of demand in different qualifications in the in the South African education system. More specifically, the BEngTech degree is awarded at a NQF level 7 (CHE, 2017) whereas the current Diploma in Engineering is awarded at NQF level 6 (CHE, 2015). The graduate attributes for the BEngTech are significantly more demanding in terms of the educational foundation – i.e. basic sciences and mathematics – to be acquired as compared to that of the Diploma in Engineering. Therefore, the scaffolding to be developed should be aligned with knowledge to be acquired by the BEngTech student and how students are expected to construct that knowledge. This means that the increased levels of complexity in terms of the new intended learning outcomes (ILOs) require not just an adjustment or modification of the syllabus but suitable alignment of the teaching and learning activities (TLAs) and the assessment tasks (ATs). This paper fleshes out these issues to assist successful curriculum development and implementation going forward.

Knowing the Knower

Curriculum in higher education may be thought of as something that shapes a student who enters a program into a graduate with specific attributes. Barnett (2009) likens curriculum in higher education to a “pedagogic vehicle for effecting changes in human beings through particular kinds of encounter with knowledge”. Both these descriptions share the essence meaning that curriculum is intended to bring about change or transformation. This simplification allows one to see that there are two key matters to consider here: (1) the desired changes, and (2) how the changes could be effectively brought about. The order of these considerations is also important. The “pedagogic vehicle” cannot be determined until the “kinds of change that we might be seeking to engender” (Bartnett, 2009) are determined. The rationale behind conceptualising the BEngTech knower in this paper flows from these considerations. Moreover, the selected approach is to make a direct link between the sought-after changes and the kinds of encounter with knowledge that would bring about these changes. Luckett (2001) provides a lens or an analytical tool with which this link can be characterised. The model of an epistemically diverse curriculum proposed by Luckett captures four ways of knowing that would be present in any curriculum. The emphasis and combinations of these four ways of knowing are different depending on the context and nature of the qualification (Quinn et al, 2016). In addition, Luckett (2001) points out that the model needs to be used in conjunction with the appropriate learning and teaching theory for its implementation. This is because the model alone cannot be used to discern how a particular kind of knowledge should be introduced to a student (Quinn et al, 2016). It is for this reason that Bloom’s taxonomy (Anderson et al, 2001) is used together with

Luckett's model. The model describes the combination and relative emphasis of the kind of knowledge and Bloom's taxonomy indicates how that particular kind of knowledge should be introduced – i.e. cognitive level.

The ultimate goal of conceptualisation the knower is to aid the development of specific educational goals and accompanying scaffolding. The work by Saywer (2014) – relating to earlier work on the Zone of Proximal Development (Vygotski, 1978) – describes scaffolding as, "The help given to a learner that is tailored to that student's needs in achieving his or her goals of the moment". This description embodies the pedagogical context in which scaffolding is used here. Scaffolding is the help BEngTech students need in achieving their educational goals towards becoming engineering technologists.

Explicating the Knower from the exit-level outcomes

Table 1 gives a summary of the key features of the qualification standards for the NDipEng and BEngTech. It is apparent from the type, designator, NQF level and credits that these two qualifications are substantially different. Logistically, these differences are apparent but how do these qualifications compare qualitatively? The exit-level outcomes (ELOs) or graduate attributes, as stipulated by ECSA, provide information which help to answer this question. It should be highlighted that ECSA uses the term graduate attributes (GAs) instead of ELOs in the new BEngTech standard. In this work, the term ELO is used in general when referring to the different qualification standards. There are 10 ELOs that are applicable to Engineering Technology qualifications in South Africa, 9 of which have been modified for the BEngTech.

The difference in the level descriptor of each standard – i.e. "well-defined" to "broadly-defined" – directly affects 5 of the 10 ELOs and represents a core change in the sought-for dispositions. How is this a core change? The level descriptor can yield further insight into the type of problem that the graduate must be competent in solving.

Table 1. Summary of NDipEng (ECSA, 2016) and BEngTech (ECSA, 2016) qualification standards.

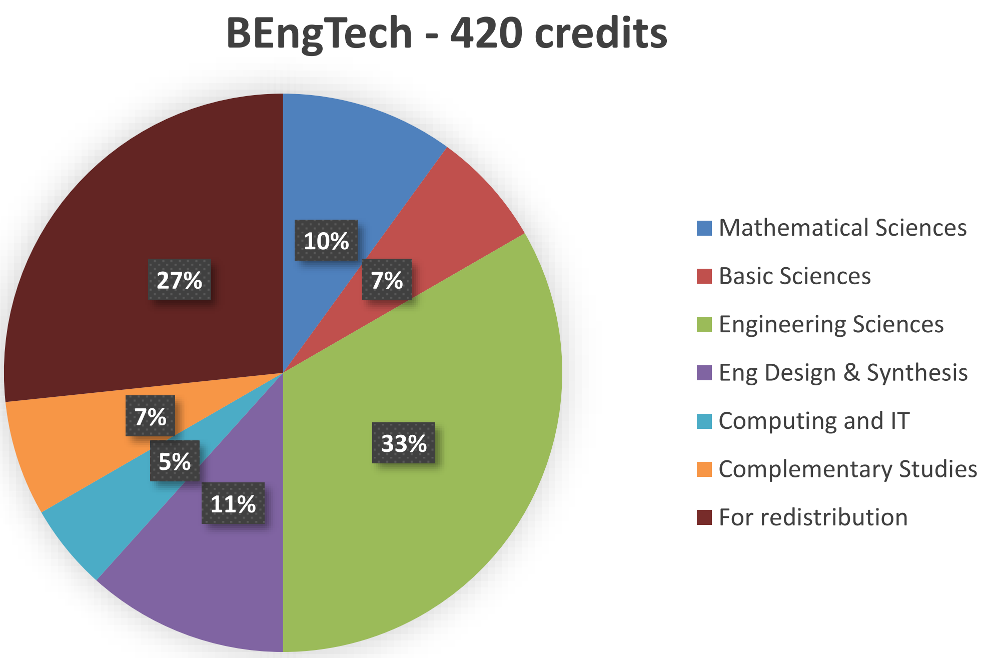
Description	**NDipEng**	**BEngTech**
Qualification Type	Diploma	Degree
Designator	None	Bachelor
Qualifier	Branch of engineering and/or substantial area (optional second qualifier).	Branch of engineering and/or substantial area (optional second qualifier).
No. of Credits	360	420
NQF Level	6	7
Exit- Level Outcomes or Graduate Attributes	-	-
1 – Problem Solving	Well-defined problems.	Broadly-defined problems.
2 – Application	Well-defined problems.	Broadly-defined problems.
3 – Design	Procedural. Well-defined.	Procedural and Non-procedural. Broadly-defined.
4 – Investigation	Well-defined problems.	Broadly-defined problems.
5 – Methods	Well-defined problems.	Broadly-defined problem.
6 – Communication	Within engineering context.	Engineering audience and affected parties.
7 – Activity Impact	Encompassed by standards and code of practice. Limited range of stakeholders. Part of engineering system. Not far reaching consequences.	Generally within, but partially outside standards and code of practice. Wide range of stakeholders. Part or wider engineering system with far reaching consequences.
8 – Individual and Teamwork	Management principles related to ELO 3.	Management principles related to ELO 3.
9 – Independent Learning	Learning context is well-structured. Some unfamiliar elements.	Learning context is varying and unfamiliar.
10 – Professionalism	Understand and commit.	Comprehend and apply.

An NDipEng graduate must be able to solve problems that are largely defined, routine and familiar in context (CHE, 2015). Problems of this nature require mainly practical engineering knowledge with theoretical underpinning, and can be solved in standardized or prescribed ways. A BEngTech graduate must be competent in solving problems that are ill-posed, or under or over specified, through coherent and detailed engineering knowledge (CHE, 2017). Similarly, the BEngTech graduate must have additional competencies in the form of non-procedural design and understanding of the impacts of engineering activity, which may be partially outside the codes of practice or standards, with a wide range of stakeholders.

References to the required practical engineering knowledge for NipEng, and detailed engineering knowledge for BEngTech, need to be unpacked to understand the difference in the envisioned knowledge components for each graduate. The charts given in Figures 1(a) and 1(b) show the different knowledge areas (in terms of credits) for the NDipEng and BEngTech programmes (ECSA-HEQF, 2009). The total number of programme credits are different, therefore percentages are used to show the distinction between the knowledge components. Besides increments in pure and engineering sciences, design and complementary studies, the major difference in the knowledge areas between programmes is engineering practice. Engineering practice constitutes 31% of the NDipEng knowledge component and does not appear in the BEngTech programme. This component corresponds to Work Integrated Learning (WIL) which the BEngTech does not have. A relatively large number of credits has been assigned “for redistribution” to the BEngTech programme and left to the discretion of the curriculum designers. This large discretionary component also features in the standards of other engineering degree programmes in South Africa (ECSA-HEQF, 2009).

These data make a quantitative distinction between the knowledge to be encountered in the two programmes but do not give much detail about the encounter itself. The cognitive levels and context of the knowledge components still need to be fleshed out. To this end, Bloom's taxonomy (Fig 2a) (Anderson et al, 2001) and Luckett's ways of knowing (Fig 2b) (Luckett, 2001) are used to better understand "levels" and "knowledge types" at play in the case of the outcomes presented in Table 1. By drawing on Bloom's taxonomy and Luckett's knowledge types, the ELOs are categorised in the cognitive levels and knowledge that the BEngTech aims to develop. These are summarised in Table 2. Ranges are allocated to most ELOs for the purpose of generalising descriptions to both the NDipEng and BEngTech outcomes.

(a)



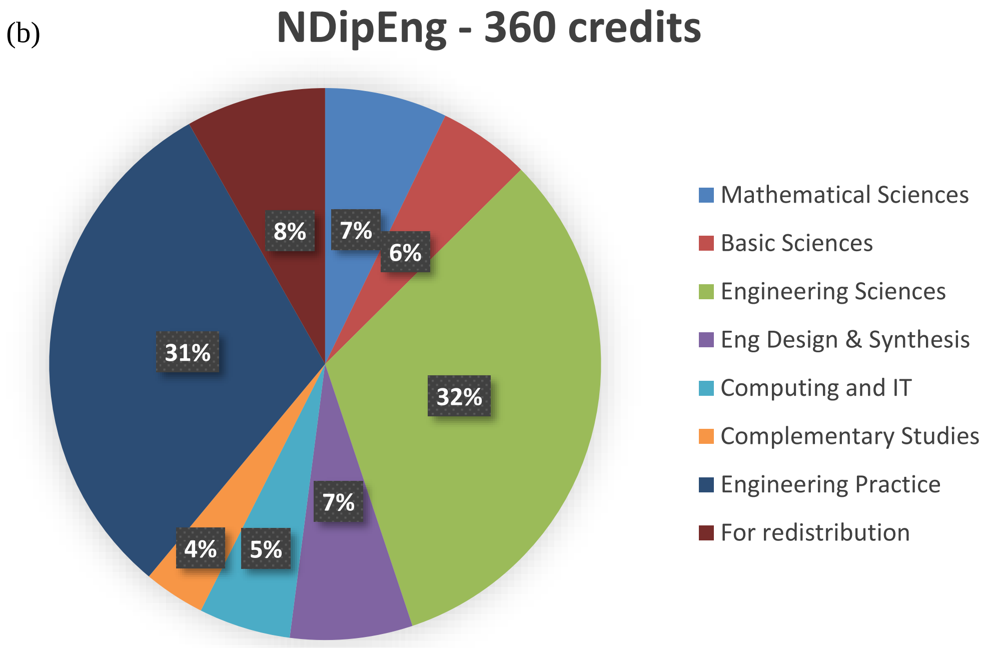


Figure 1. The knowledge areas stipulated by ECSA qualification standards, in terms of credits, of the (a) BEngTech, and (b) NDipEng, programmes.

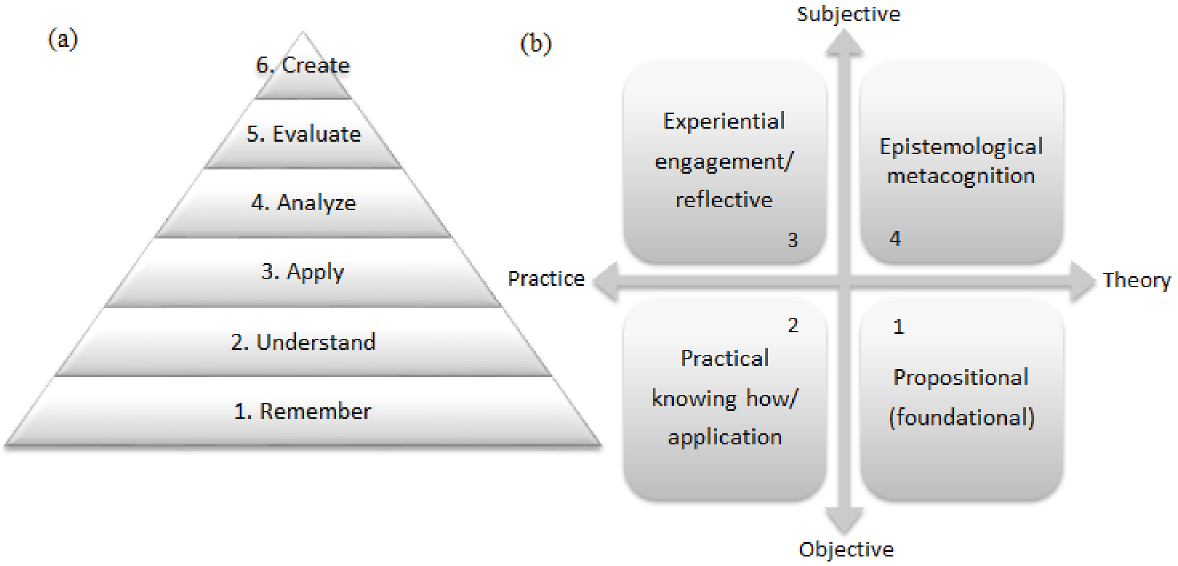


Figure 2. (a) Bloom’s taxonomy, and (b) Luckett’s knowledge plane.

Table 2. Assignment of Bloom's taxonomy levels and Luckett's knowledge plane quadrants to ELOs.

Exit- Level Outcomes or Graduate Attributes	**Bloom's Taxonomy Level**	**Luckett's Knowledge Type**
1 – Problem Solving	6 and below	Mainly 1 – 3, possibly 4
2 – Application	3	Mainly 1 – 3, possibly 4
3 – Design	6	All 4
4 – Investigation	3, 4	Mainly 1 – 3, possibly 4
5 – Methods	1 – 4	2
6 – Communication	3	Mainly 1 – 3, possibly 4
7 – Activity Impact	5	3 – 4
8 – Individual and Teamwork	3 – 5	1 – 3
9 – Independent Learning	1 – 5	2, 3
10 – Professionalism	1 – 5	3 – 4

The question now arises: How does the change in the ELO level descriptor influence the taxonomy level and knowledge type for a particular ELO? To help answer this question, the case of ELO 1, problem solving, is analysed. ELO 1 for NDipEng is "Apply engineering principles to systematically analyse and solve well-defined engineering problems" (CHE, 2015). For BEngTech, the key difference is the level descriptor – i.e. "broadly-defined engineering problems" (CHE, 2017). The verbs for this particular ELO – "apply", "analyse", and "solve" - refer to Bloom's taxonomy levels 4 and 5. However, if a problem is broadly-defined, as in the case of the BEngTech, this will most likely require the graduate to have some ability to "reframe", "construct" and "adapt" problems and/or solutions. Therefore, this difference in the ELO 1 level descriptor has the implication of elevating the Bloom's taxonomy level. What about implications on the knowledge type? In the case of well-defined problems, the learner will “apply”, “analyse”, and “solve” familiar problems with known solutions. A BEngTech graduate should be able to engage in solving unfamiliar problems and should therefore have a firm grasp of underlying principles and theoretical knowledge. This is what is meant by the previously mentioned “detailed engineering knowledge”. Due to the nature of problems, the necessary solutions will require more creativity and a somewhat subjective approach. Metacognitive knowing will also be tested as BEngTech students will be expected to think critically about relatively complex problems. This means that the difference in the level descriptor for ELO 1 prompts a dual shift and expansion in ways of knowing represented by quadrants 1, 3 and 4 in Luckett’s plane. This may be considered as a simultaneous movement towards more theoretical and subjective ways of knowing. Through these analyses, a conceptual mapping for the NDipEng and BEngTech (provided in Figure 3) on Luckett’s plane is derived.

How does the map in Figure 3 help towards understanding the knower to be developed? This work began with trying to conceptualise the BEngTech knower. The process of mapping creates a relative conceptualisation by making a distinction between the NDipEng and BEngTech knowers. Albeit contrived, the conceptual map in Figure 3 does give a sense of the implications on the new curriculum resulting from the changes in the ELOs and knowledge components.

Mapping also correlates knowledge weightings to outcomes and offers a means of problematizing selection of recontextualised knowledge. But there are still the outstanding issues of sequencing and pacing which are critical to curriculum planning (Muller, 2009) that need to be considered. Why are these aspects so critical? Successful epistemic transition requires careful sequencing and pacing through scaffolded support (Winberg et al, 2016). In order to determine and pedagogise the appropriate support, it is necessary to first consider the potential transitional barriers and bottlenecks to epistemological access.

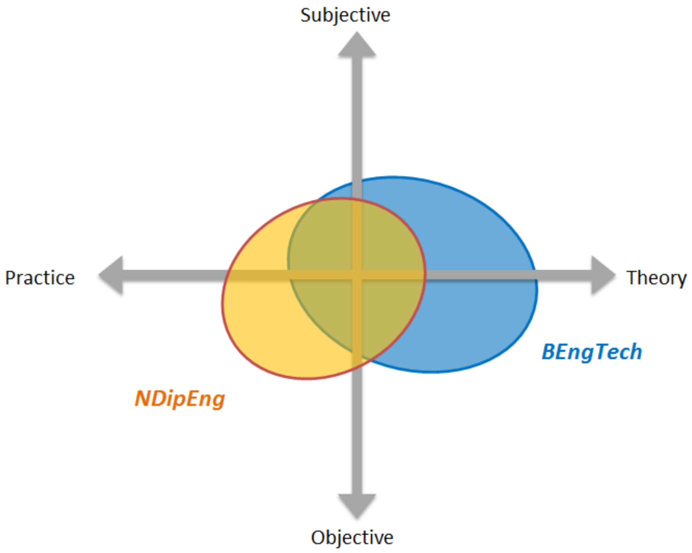


Figure 3. Conceptual mapping of the BEngTech and NDipEng ways of knowing.

Developing effective scaffolding

The difficulties encountered by students when confronted with engineering knowledge is well documented in the literature (Winberg, 2016; Carstensen and Bernhard, 2008; Flanagan et al, 2010). Winberg (2016) suggests that these difficulties arise from the complexity of the context and pose significant cognitive challenges. In the context of the presented case, the question arises as to what cognitive challenges are expected. Is it expected that cognitive challenges of the new curriculum will differ from that of old? These should differ according to the ECSA qualification standards. How are these cognitive challenges different? The shift from practical ways of knowing to theoretical will evoke a shift from contextual to conceptual knowledge. A mix of differential knowledge forms – i.e. conceptual and contextual, is a distinguishing feature of professionally oriented curricula (Gamble, 2009). Gamble (2009) suggests that these knowledge forms are required for knowledge progression and occupational progression. Gamble postulates three kinds of applied competence (practical, foundational and reflexive) to capture this. In the case of the BEngTech, the conceptual and contextual coherence could therefore be found via interpretation of the outcomes. The mapping shown in Figure 3 indicates that some knowledge mix is required to shape the BEngTech graduate which is different to that required to shape an NDipEng graduate. The mapping itself is informed by the interpretation of the outcomes. This is somewhat complimentary to Maton's (2007) idea of knowledge and knower structures because outcomes can be seen as different points on the knower structure to be developed.

The Higher Education Qualifications Framework (HEQF) of South Africa provides limited differentiation between qualifications but does stipulate that the coherence requirements and the mix (conceptual and contextual) for each qualification is critical in determining relevant knowledge and skills and distinguishing pathways to different levels of specialisation (CHE, 2011). In CHE (2013), the issue of conceptualised versus contextualised programmes is dealt with in more detail. For instance, the CHE (2013) stipulates that contextual knowledge is more relevant for task-specific proficiency whereas conceptual knowledge is more relevant for knowledge-specialisation. For professionally-oriented curricula, the question arises to the "proportional emphasis on contextual and conceptual knowledge" (CHE, 2013).

So can further deductions be made regarding the conceptual and contextual coherence for the problem at hand? The results of the conceptual mapping exercise show that ways of knowing that characterise the BEngTech graduate are more conceptually relevant than contextually when compared to the NDipEng graduate. The BEngTech is intended to be more "knowledge-specialised" to enable technology specialisation after workplace training and experience, and articulation into postgraduate research programmes. The NDipEng program emphasises more task-specific proficiency and therefore is characterised by contextual relevance. There is an assertion on continued professional development for BEngTech in contrast to the emphasis on work-based skills and situational and procedural knowledge with the NDipEng graduate. Scaffolding for BEngTech students should be developed based on cognitive challenges arising from the new context-concept mix.

A further factor affecting development of scaffolding is the postgraduate qualification BEngTech (Hons) which follows the BEngTech qualification (ECSA, 2013). The BEngTech (Hons) is awarded an NQF level 8 whereas the current Bachelor of Technology: Engineering (BTech:Eng), following the NDipEng, is awarded at NQF level 7. The new engineering technology qualification at honours level is intended to enable articulation to masters degree programmes (ECSA-HEQF, 2009). Hence, the graduate attributes for the BEngTech (Hons) are aligned with the undergraduate qualifications Bachelor of Science in Engineering (BScEng) and Bachelor of Engineering (BEng) – i.e. the level descriptors of the ELOs stipulated in the each of qualification standards refer to “complex problems”. The standard implies that the BEngTech (Hons) programme will scaffold a BEngTech graduate, to solve “broadly-defined” problems, while an honours graduate can solve “complex” problems. The BEngTech (Hons) must effectively make changes in the foundational knowledge of the graduate, rather than build solely on existing knowledge - to be in compliance with the qualification standard. The CHE qualification standard for the BEngTech (Hons) is currently being drafted and will certainly have to take these issues into account.

Conclusion

The Diploma is used as a point of reference and comparisons are made rather than treating of BEngTech in isolation. The reasoning here is based on the fact that the

BEngTech is unlike any other of the previous engineering technology education “shake-ups” that have occurred over the years. The shift in focus relating to graduate attributes and knowledge constituencies shown here will influence the design of TLAs and ATs in order for long term success of the new curriculum. This method of correlating ways of knowing and the ILOs could potentially assist with reinvigorating knowledge differentiation discourse in curriculum development, particularly for professionally oriented curricula, where knowledge discourse has been subordinated to outcomes (shay, 2013; Allais et al, 2009). Shay (2011) highlights the need for extending “theoretical tools” in higher education studies that aid with the analyses of relationships between disciplinary knowledge and curriculum. Additionally, Shay points out the importance of understanding what educational knowledge shifts arise from curriculum transformation and how these affect student identity. The presented conceptual mapping process lends itself to the task of exploring knowledge-curriculum relationships such as to better understand the kind of knower being promoted.

Although the issue of conceptual and contextual knowledge coherence has become clearer, there is still the question of how this can actually be related to pedagogic practice. More specifically, can this coherence into the BEngTech curriculum be quantified and eventually regulated, because there is more to curriculum structure than can be inferred from just the knowledge structure (Luckett, 2009). This related to selection, sequencing and pacing. Maton’s Legitimation Code Theory (LCT) (2014) offers some tools with which to further demystify this issue of coherence. For instance, Winberg et al. (2016) found, through LCT, how suitable selection, sequencing and pacing can provide the necessary conceptual-contextual coherence. The next step of this work will be to investigate how to effectively select, sequence and pace so that the new curriculum will create the knower conceptualised in this paper. The mapping process offers a first step is conceptualising the BEngTech knower and paves the way for coherence discussions in the milieu of different engineering technology branches such as mechanical, chemical, industrial, mining and electrical.

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