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Renewable Energy Technologies: How technical curricula could enable a brighter future

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Abstract

The potential of renewable energy technologies to mitigate climate change while meeting the energy demand of future generations is recognised globally. In South Africa, occupations such as wind turbine technicians and solar photovoltaic installers are in high demand. In response to these needs, Renewable Energy Technologies (RET) subjects were developed as specialised electives within the Electrical Infrastructure Construction programme that is offered by technical and vocational education and training (TVET) colleges. The focus of this study is the knowledge that underpins the RET subjects. The guiding research question is: What forms of knowledge underpin the RET curricula, and what is the relationship between these knowledge forms? The semantic dimension of Legitimation Code Theory was used to explain the knowledge forms underpinning the RET subjects. The study uncovered gaps and imbalances across the range of knowledge forms selected, while the relationships between the knowledge forms constrained cumulative knowledge building. The contribution made by the study is a principled understanding of how knowledge selection and sequencing in technical curricula could enable cumulative learning and build valued competencies within the renewable energy field.

Keywords: *renewable energy technologies, technical and vocational education and training, wind turbine technicians, solar photovoltaic installers*

Introduction: Greening TVET

The potential of renewable energy technologies to mitigate climate change while meeting the energy demand of future generations is recognised globally. Many countries have consequently initiated technical and vocational educational training (TVET) programmes to meet the demand for skilled renewable energy technicians. In South Africa, in the light of failing electrical infrastructure and environmental damage caused by coal-generated power, renewable energy is of increasing importance for social and economic development. The need for skilled technicians in the field is a major driver for future occupations in the green economy (Durrans et al., 2020). According to the Renewables Global Status Report (REN21) “the renewable energy sector employed (directly and indirectly) around 11 million people worldwide in 2018” (REN21, 2019, p. 17). Occupations in solar and wind-generated power are in high demand as new and more sustainable forms of electricity supply are

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sought. But while renewable energy provision has gained prominence, knowledgeable and skilled technicians in the sector are in short supply. In fact, occupations such as wind turbine technicians and solar photovoltaic installers are at the highest level of demand in South Africa (Department of Higher Education and Training [DHET], 2019).

Since 2013, the German Ministry of Economic Cooperation and Development's Programme *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) and Skills for Green Jobs (S4GJ) have, in cooperation with the South African Department of Higher Education and Training (DHET) and Department of Science and Technology (DST), run a pilot project on the greening of TVET colleges. The collaborators developed specialised elective subjects in Renewable Energy Technologies (RET) for the National Curriculum Vocational in Electrical Infrastructure Construction (NCV-EIC). Thus, a key area of TVET provision for the green economy is the RET subjects that are offered at introductory, intermediate and advanced levels. These subjects are the focus of this study.

The field of renewable energy technologies brings together many of the key debates in TVET curricular studies, including how a technical curriculum might prepare young people for competent practice and employability in a growing sector, the kinds of scientific underpinning such a curriculum should have, the role that practical training might play, as well as broader issues of citizenship and sustainable development. The research question guiding this study is: What forms of knowledge underpin the RET curriculum, and what is the relationship between these knowledge forms?

The literature on renewable energy technologies education

Renewable energy sources include bioenergy, geothermal energy, hydropower, solar energy, ocean (tide and wave) energy and wind energy. The demand for renewable energy technologies to meet human needs and industrial and commercial processes is growing in South Africa and internationally (Fouché & Brent, 2019). Renewables are key "to help mitigate climate change" and "to meet [the] energy demand of future generations" (Owusu & Asumadu-Sarkodie, 2016, p. 2). Many countries have consequently initiated vocational programmes in renewable energies (Kandpal & Broman, 2014).

There are many routes to becoming a renewable energy technician. Technicians generally require a post-secondary qualification (Stroth et al., 2018), but students could undertake an apprenticeship comprising classroom learning and hands-on work under the supervision of experienced technicians (Jennings, 2009), or be trained by one of the companies providing wind or solar power (REN21, 2019). For colleges to provide relevant and appropriate training for renewable industries, a range of formal programmes, as well as short term, on-the-job training courses for updating knowledge and skills, are required (Kandpal & Broman, 2014).

The knowledge base for the initial education of technicians for renewable energy technologies comprises both scientific and practical knowledge (Malamatenios, 2016). Mathematical knowledge is important for performing energy calculations, while electrical engineering knowledge is basic to the full range of occupations in the renewable energy field. In the practical training of heat pump installers, for example, errors tended to occur when the scientific basis of practice was not clear to technicians (Gleeson, 2016).

The practical knowledge needed by renewable energy technicians is field-specific to underpin the ability "to construct, install and maintain the equipment that collects, generates, or distributes power through renewable means" (Malamatenios, 2016, p. 4). Including practical knowledge in the curriculum is particularly important for the transfer of concepts to practice. Transfer requires students to engage in diverse episodes of practice that explicitly build causal links and associations to the underpinning concepts (Vosniadou & Skopeliti, 2014). Building causal links is central to problem-solving and competent practice (Billett, 2018). Students' dispositions towards the occupation are likely to be shaped by their practical learning experiences, observing others, and making judgements about the value of concepts and practices and how these can be reconciled with what they experience (Billett, 2018). Opportunities to engage in practice tend to motivate students, but when such opportunities are not readily available, students' engagement through gamification and simulation is recommended (Spangenberger et al., 2020).

The relationship between scientific and practical knowledge is crucial in technical curricula. Ongoing debates around the degree to which curricula should be determined by disciplinary knowledge, or by occupational standards are evidence of the neglect of the relationship between theoretical and practical knowledge in vocational education (Winch, 2013, p. 281). With regard to renewable energy, Jennings (2009) advised that training should include courses in construction safety, energy systems, English, mathematics, installation techniques, site analysis and design. Employers usually require applicants to have had some experience in the field of renewable energy technologies, thus educational provisions include "laboratories, practical demonstration of operational systems, field visits and field installation of actual working systems, and hands-on-skills training such as trouble-shooting, design, and manufacture besides lectures, tutorials, assignments, and seminars" (Kandpal & Broman, 2014, p. 7). Recent studies suggest that climate science and environmental assessment studies should be integrated into technical programmes and that "disruptive innovations, extremes, and broad sustainability questions must be explored" (Nikas et al., 2021, p. 119).

A number of studies found gaps between more theoretically oriented academic curricula and the practical competences required by industry (Durrans et al., 2020; Fitch-Roy, 2013; Kandpal & Broman, 2014; Lucas et al., 2018). Research undertaken on the impact of the gaps in education and training in renewable energy industries worldwide shows that many renewable energy courses fail to deliver the kind of practical hands-on training that is needed to address skills shortages (Lucas et al., 2018). These include installation, operation, construction, and maintenance. It is recognised that vocational training provides a valuable form of education, with a specific focus on practical hands-on training. However, "only about 15% of existing courses fall into this category" (Lucas et al., 2018, p. 453). Consequently, there is a need for industry and TVET to collaborate in order to address the misalignment between education and training offerings and industry needs and standards. South African

TVET programmes have been found to require “more consideration of the nature and trajectory of sectors, firm dynamics [and] their particular occupational structures” (Allais et al., 2021, p. 650). The field of renewable energy is “cross institutional, cross sectoral and also inter- and transdisciplinary” which necessitates innovative approaches and “transformative, transgressive forms of learning that move beyond the boundaries of single institutions” (Lotz-Sisitka, 2020, p. 143).

A theoretical framework to guide theory and practice in a technical curriculum

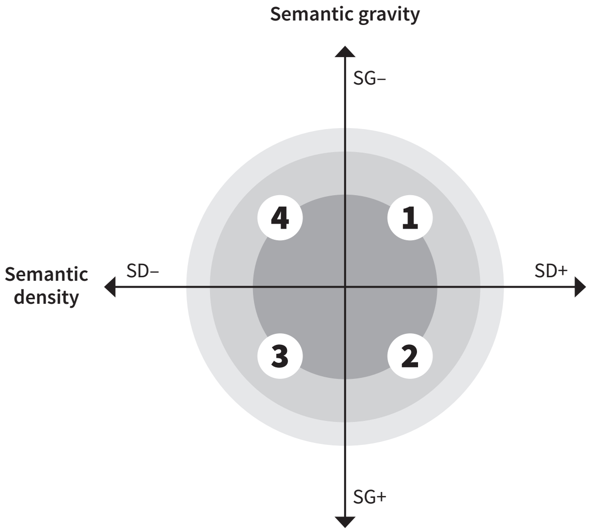
Legitimation Code Theory (LCT) was chosen as the theoretical framework for this study. LCT has been extensively used to investigate the knowledge that underpins various types and levels of educational curricula (Maton, 2014), including vocational education (e.g., Johansson, 2020). LCT offers a range of concepts and tools for examining practices, with each dimension exploring the organising principles that underpin dispositions, practices and fields.

The internal language of description

The semantics dimension of LCT is particularly appropriate for this study as it attempts to identify the unpinning knowledge structures of curricula. The organising principles of semantic structures are “conceptualized as semantic codes comprising semantic gravity and semantic density” (Maton, 2014, p. 2). Semantic gravity refers to the degree of context-dependence, while semantic density refers to the degree of condensation of meaning (Maton, 2014). While semantic density is often understood as equivalent to ‘theory’ and semantic gravity as equivalent to ‘practice’, this is not the case. Both theoretical and practical knowledge can have stronger and weaker elements of semantic density and semantic gravity. How they are applied in specific curricula will vary. For example, an installation procedure might have strong semantic gravity and strong semantic density if it is both contextually complex and underpinned by scientific knowledge. The same procedure could be simplified, thus have a weaker semantic gravity and weaker semantic density when introduced into the curriculum at an introductory level. The same applies to disciplinary concepts.

The success of a vocational curriculum depends on an appropriate relationship between semantic gravity and semantic density. Effective relationships between semantic gravity and semantic density promote ‘cumulative learning’ (Maton, 2014, p. 143), and enable relationships between theory and practice (Waite et al., 2019). Semantic gravity and semantic density are conceptualised as two intersecting continua, creating a semantic plane (Figure 1). Different forms of semantic gravity and semantic density can be located at a range of positions on the two continua, resulting in many possible combinations. The four key combinations are labelled as quadrants 1, 2, 3 and 4.

Figure 1: *The semantic plane.*[1] *Source: Maton, 2014, p. 131*



The first quadrant has weaker semantic gravity (or contextual content) and stronger semantic density (or conceptual content), which is typical of the basic sciences. The second quadrant has both stronger semantic gravity and stronger semantic density, which is characteristic of the applied sciences, such as the engineering sciences that have high levels of both contextual and conceptual complexity. Quadrant three has stronger semantic gravity and weaker semantic density, making it typical of knowledge developed in practice. The fourth quadrant has both weaker semantic gravity and weaker semantic density, which usually indicates generic subject matter that is not directly related to the technical area, although the subject could be valuable, such as communication skills. Table 1 represents the semantic plan in tabular form.

Table 1: *Semantic gravity and semantic density combination*

Quadrant	Semantic combinations	Codes	Examples
1	Weaker semantic gravity, and stronger semantic density	SG-,SD+	Basic sciences
2	Stronger semantic gravity, and stronger semantic density	SG+,SD+	Engineering sciences
3	Stronger semantic gravity, and weaker semantic density	SG+,SD-	Practical knowledge
4	Weaker semantic gravity, and weaker semantic density	SG-,SD-	Generic knowledge

Table 1 represents the range of knowledge forms that technical curricula would draw on: scientific concepts, applied sciences, codified forms of procedural knowledge and knowledge arising from practical tasks and activities, as well as generic content. Engaging in the full range of knowledge forms, conceptualising, applying concepts to practice (as in the engineering sciences), preparing for practice (through study of standardised procedures) and implementing the procedures (e.g., constructing, installing, maintaining, repairing) builds occupational competence (Johansson, 2020). Generic knowledge about the field, such as its history, policies and development, can broaden students' understanding of their future occupations. It is "the strengthening and weakening of *both* semantic gravity and semantic density … that makes possible knowledge-building across different contexts and over time" (Maton, 2014, p. 143). Typically, a concept is introduced and simplified, but, as Waite et al. explained: a technical curriculum needs to be iterative with each concept "building on the previous one, rather than assuming that once a technical, abstract concept has been explained it can be used from there on" (Waite et al., 2019, p. 4); there has to be continuous traversing of the knowledge range for students to 'make the links'. For example, following a practical exercise, students need to debrief and evaluate what they accomplished against codified procedures (Lucas et al., 2018). Reflecting by drawing on the full semantic range enables students to draw on scientific and engineering concepts in order to formulate solutions to the challenges they confront in practice (Waite et al., 2019).

Methodology

This study is part of a national project on evaluating TVET colleges supported by the TVET division of DHET. The data for this curriculum evaluation was obtained from the RET Subject Guides and Assessment Guides, as well as the textbooks developed by the S4GJ/GIZ collaboration. The curriculum documents are listed in Table 2.

Table 2: *Curriculum data*

Curriculum Documents	NQF Level	Year	Abbreviation
Renewable Energy Technologies Subject Guide (2015)	2	1	RET-SG 2, 2015
Renewable Energy Technologies Assessment Guide (2015)	2	1	RET-AG 2, 2015
Renewable Energy Technologies Subject Guide (2016)	3	2	RET-SG 3, 2016
Renewable Energy Technologies Assessment Guide (2016)	3	2	RET-AG 3, 2016
Renewable Energy Technologies Subject Guide (2017)	4	3	RET-SG 4, 2017
Renewable Energy Technologies Assessment Guide (2017)	4	3	RET-AG 4, 2017
Text books			
S4GJ & GIZ (2016). *Renewable Energy Technologies National Certificate (Vocational): Introduction to Renewable Energy and Energy Efficiency (Levels 2 and 3)*. Pretoria: DHET	2 & 3	1 & 2	S4GJ/GIZ 2/3
S4GJ & GIZ (2017). *Renewable Energy Technologies National Certificate (Vocational): Introduction to Renewable Energy and Energy Efficiency (Levels 4)*. Pretoria: DHET	4	3	S4GJ/GIZ 4

Note that the guides are identified by National Qualification Framework (NQF) level, not by year level. The South African NQF comprises 10 levels. Basic compulsory education from grades 1 – 9 are included in NQF level 1. Senior school, from grades 10 – 12, are at NQF levels 2, 3 and 4, respectively. Levels 5 – 10 cover higher education from first year (level 5) to doctoral studies (level 10). Vocational education currently resides in the same band as senior school, that is, NQF levels 2 – 4. The first year RET Study Guide is thus at NQF Level 2. The RET electives enable students to specialise in renewable energy technologies within the field of Electrical Infrastructure Construction. The guides explain that the RET subjects include a theoretical component (30 – 40%), which is externally assessed, and a practical component (60 – 70%), which is internally assessed. A year mark out of 100 is calculated by adding the marks of the theoretical component and the practical component of the internal continuous assessment.

Outcomes: The external language of description

All TVET curricula are outcomes-based; study and assessment guides largely comprise exit level outcomes, learning outcomes and assessment criteria. Table 3 shows the distribution of the 34 exit-level outcomes across the three RET modules.

Table 3: *Exit level outcomes across the RET modules*

NQF Level 2	NQF Level 3	NQF Level 4
Topic 1: Introduction to renewable energy resources and energy efficiency		
1. Explain international and national climate change policies. 2. Explain the differences between energy resources. 3. Explain the significance of solar radiation.	13. Explain the economic and environmental benefits of solar water heating (SWH) systems. 14. Demonstrate the realistic potential for this technology in South Africa. 15. Prepare a simple cost/benefit analysis for a residential SWH installation. 16. List and describe relevant norms, standards and regulations for South Africa's SWH-Industry.	24. Explain the economic and environmental benefits of wind power generation. 25. Demonstrate the realistic potential for this technology in South Africa. 26. Explain the economic and environmental benefits of electro-mobility and fuel-cell technology. 27. Compile an overview of advantages and disadvantages of hydrogen and fuel cell technology.
Topic 2: Basic scientific principles and concepts		
4. Explain energy concepts and investigate energy efficiency options. 5. Explain the concept of electricity and its base values. 6. Build simple DC circuits and perform calculations.	17. Understand and apply the basic principles of SWH and relate those to the key components of SWH systems. 18. Explain the basic principles for roof mounted collector installation. 19. Perform basic calculations relevant for system sizing.	28. Explain the basic principles of wind power generation. 29. Explain the basic principles of hydrogen and fuel cell technology. 30. Explain eMobility concepts.

NQF Level 2	NQF Level 3	NQF Level 4
Topic 3: Safety		
7. Describe and demonstrate safe work practices.	20. Describe and demonstrate safe work practices for working at heights.	31. Develop technology relevant workplace health and safety processes and procedures.
Topic 4: Basic principles of Photovoltaic (PV) systems	**Topic 4: Applications of SWH-systems**	**Topic 4: Application of wind turbine and fuel cell systems, and batteries**
8. Explain the basic principles of Photovoltaic (PV) systems. 9. Identify and explain the use of training kit components and/or industrial components for experiments. 10. Explain the characteristic of solar cells under different conditions. 11. Demonstrate the effect of series and parallel connections of solar cells under different conditions. 12. Emulate the effect of diurnal variation and design a simple off-grid network.	21. Identify the different components of solar hot water systems and explain their specific application/function. 22. Explain the different types of thermo-siphon systems and describe measures to ensure frost, hail, and scale resistance. 23. Prepare and install a pre-fabricated low-pressure thermo-siphon system on a training roof.	32. Connect wind turbine components using didactical training kits or small-scale industrial components. 33. Connect fuel cell system components using didactical training kits or industrial components. 34. Explain the operation and performance of batteries for renewable energy systems.

Each exit level outcome has five to ten learning outcomes. The learning outcomes are numerous and comprise the main content of the RET subject guides. Each learning outcome has associated assessment criteria that make up the main content of the assessment guides. The texts and tasks in the RET textbooks follow the learning outcomes; the textbooks start with learning outcome 1.1 and conclude with learning outcome 34.13. The textbooks include texts and tasks that 'flesh out' the learning outcomes. Each learning outcome, as well as its accompanying texts and tasks in the textbooks, was studied to determine the relative strength of its semantic gravity and semantic density, as explained in the following section.

A translation device: Linking the internal and external languages of description

A 'translation device' (Maton & Chen, 2016) was developed to apply the concepts of semantic gravity and semantic density to the study of the curricular outcomes (Table 4). Accordingly, the tables of exit level outcomes, learning outcomes, and assessment criteria and accompanying textbook texts and tasks were studied and coded to identify the kinds of knowledge underpinning the outcome.

Table 4: *Translation device for a renewable energy technology curriculum*

Semantic range	Knowledge types	Semantic codes	Quadrant	Examples of learning outcomes
↕	Conceptual	SG-, SD+	1	Basic scientific concepts, e.g., 'Describe the principle of energy conservation' (30.2).[2]
	Applied	SG+, SD+	2	Engineering science principles e.g., 'Explain arrangement required to connect wind turbines to the grid (installation of transformer, medium and high voltage switchgear, high and low tension power lines' (28.8).
	Practical	SG+, SD-	3	Codified procedures or knowledge acquired in practice, e.g., 'Perform testing and fault finding on all of the above set-ups, installed small-scale installations' (32.12).
	Generic	SG-, SD-	4	Generic knowledge, e.g., 'Design health and safety checklists that can be used at the learning institution' (31.4).

The translation device describes the range of knowledge types needed in technical fields (e.g., Johansson, 2020), including renewable energy technologies (e.g., Gleeson, 2016; Kandpal & Broman, 2014). The double arrow in the 'Range' column indicates that iterations across the full range of knowledge types are necessary (Waite et al., 2019). Each code was given a numerical value that corresponds to the four quadrants of the semantic plane (Figure 1).

Using the translation device to analyse the data

To analyse the data, we studied each of the 34 exit level outcomes, their learning outcomes and associated assessment criteria. We also studied the relevant sections of the two textbooks, which provided more detail on the types of activities, exercises, calculations and experiments to be undertaken at each level of the RET subjects. The outcome descriptions, assessment criteria and key aspects of the textbooks were captured on an Excel file and coded for semantic gravity and semantic density, and knowledge type (Table 5). The codes were consolidated across learning outcomes, assessment criteria, and textbook activities and then re-checked and refined. For example, learning outcome 32.4.2.8, 'Operate the electrolyser with a miniature wind turbine' was initially coded as having stronger semantic gravity and weaker semantic density (SG+,SD-), but was subsequently recoded as reducing the semantic gravity and strengthening the semantic density, shown by the upward and downward arrows respectively (SG+↓, SD-↑). The reason for weakening the semantic gravity was because of the oversimplification of the device used for the wind experiments, while the reason for strengthening the semantic density was because the function of the wind experiments was to consolidate and deepen students' understanding of theoretical concepts.

The analysis enabled us to identify each knowledge type, with reference to its quadrant on the semantic plane (Figure 1), as well as its curricular level, which was indicated by impact of the activities, exercises and experiments on strengthening or weakening semantic gravity and density. The first finding thus explains the characteristics of the knowledge types across the RET modules, while the second finding focuses on the curricular level.

Table 5: *Example of how data were analysed*

No.	Learning outcome	Reference	Assessment criteria	Reference	Textbook	Reference	Semantic code	Quadrant
28.2.1.2	Describe the principle of energy conservation.	RET-SG4, p. 9	The principle of energy conservation is described.	RET-AG4, p. 12	Equations and exercises to explain first law of thermodynamics.	S4GJ/GIZ 4, pp. 94-96	SG-;SD+	1
Notes: Basic scientific knowledge; conflation of outcomes and assessment criteria; the topic was mainly covered in RET3 - brief summary/definition in RET4.								
32.4.1.4	Determine the output power of a generator at different wind speeds.	RET-SG4, p. 10	Output power of a generator at different wind speeds is determined.	RET-AG4, p. 16	Explanations of energy transfer; exercises and calculations with application to wind turbine.	S4GJ/GIZ 4, pp. 97-103	SG+,SD+	2
Notes: Applied knowledge; conflation of outcomes and assessment criteria; text book provides exercises and calculations.								
32.4.2.8	Operate the electrolyser with a miniature wind turbine.	RET-SG4, p. 11	Operation of electrolyser with a miniature wind turbine (in combination with the wind turbine training kit).	RET-AG, p. 18	Introduction to training kit, assembly, exercises, experiments and calculations.	S4GJ/GIZ 4, pp. 136-145	SG+↓,SD-↑	3
Notes: Practical knowledge (but not work-oriented); experiments and exercises consolidate sciencific and applied scientific knowledge; far removed from actual practice.								
24.1.1.6	List and compare the advantages and disadvantages of wind power generation.	RET-SG4, p. 9	The advantages and disadvantages of wind power generation are listed and compared.	RET-AG4, p. 10	Textbook has text only on reducing GHG emissions, mitigation of climate change, environmental impact assessment, public participation processes, etc.	S4GJ/GIZ 4, pp. 50-57	SG-,SD-↑	4
Notes: Generic knowledge; outcomes and assessment criteria are conflated; textbook is text heavy, no exercises, small research projects, or activities.								

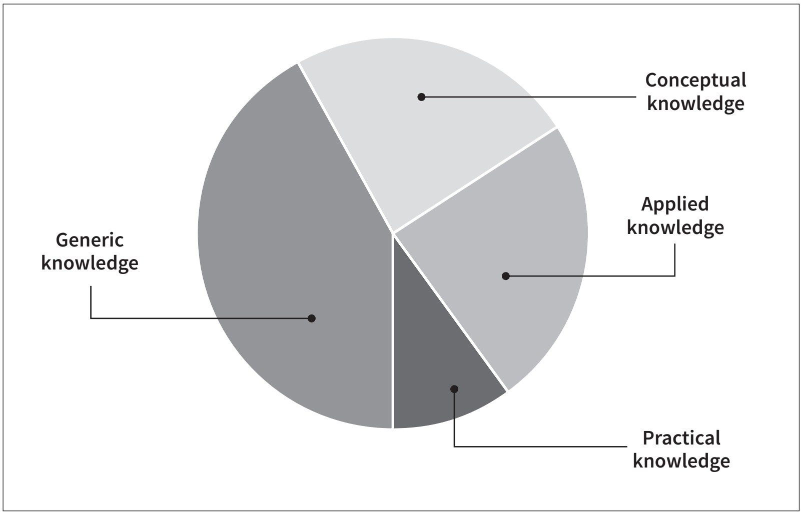
Finding 1: Knowledge across the RET subjects

The purpose of the RET subjects is explained as follows:

> Renewable Energy Technologies has been designed as an optional vocational subject that … addresses the necessary trade-specific skills, knowledge, values and attitudes [in order to place students] in a better position for future job placements in the green economy. (RET-SG 4, 2017, pp. 2-3)

Figure 2 illustrates the range of exit level outcomes. Generic outcomes take up considerable curricular space (42%), conceptual and applied knowledge outcomes comprise 24% each, while practical knowledge has very little curricular space (10%). Of the 34 exit level outcomes, 14 outcomes have to do with renewable energy policies, regulations, legal frameworks, costs and benefits, or general safety issues. Of the remaining 20 outcomes, eight outcomes are underpinned by basic sciences, eight by engineering sciences, and only four outcomes involve practical knowledge, such as: 'Prepare and install a pre-fabricated low-pressure thermo-siphon system on a training roof' (23). Some outcomes that appear to be practice-oriented, such as 'Build simple DC circuits' (6), are exercises or laboratory experiments that help students to consolidate theoretical knowledge and are not work-oriented.

Figure 2: *Distribution of knowledge types across the exit level outcomes*



Many forms of knowledge underpin RET, but the exit level outcomes favour the generic above the occupational-specific. Thus the majority of outcomes are located in quadrant 4 of the semantic plane (Figure 1), that is, that have both weaker semantic gravity (SG-) and weaker semantic density (SD-). Many of these generic outcomes have value outside of the engineering knowledge base and such generic outcomes can be useful for planning

(Nikas et al. 2021), or for reflection on the contribution made by particular technologies (Durrans et al., 2020). A stated intention is to help students to understand that renewable energy is a crucial part of "South Africa's future energy mix and green economic growth" (RET-SG 4, 2017, pp. 2-3), but it has been pointed out that generic provision tends to have 'little sectoral specificity and little integration into economic development strategies' (Allais et al., 2021). Stronger semantic gravity, for example, in the form of work-oriented tasks derived from actual work practices, is necessary to better align curricular and occupational outcomes (Durrans et al., 2020). The spread of outcomes is not consistent with the claim that the RET subjects comprise-30-40% theory and 60-70% practice.

The RET Subject and Assessment Guides, as well as the supporting textbooks, are packed with the exit level and learning outcomes. For example, RET 4 has four topic areas comprising eleven exit level outcomes and 79 learning outcomes and assessment standards. This level of detail makes time consuming and perplexing demands on lecturers (Atkinson, 2016). Each outcome is understood separately and has no explicit relationship to the one before or after. Substituting lists of outcomes for a curriculum will not enable cumulative learning as relationships across the knowledge range are missing (Johansson, 2020; Waite et al., 2019). Treating each outcome separately is likely to reinforce the theory-practice divide. For example, a module might begin with an outcome underpinned by basic scientific knowledge (SG-,SD+), such as energy conversion and heat transfer; then progress to outcomes related to the engineering principles of solar water heating devices, such as including laboratory experiments to investigate the principles of solar water heating devices (SG+, SD+). Outcomes related to procedures for installing the essential components of a flat plate collector might then follow (SG+,SD-). But they do not go back and forth across the semantic range to reflect on practice in relation to procedures, engineering science, or relevant scientific concepts.

The pattern we detected across the three RET modules was: 1) the guides and textbooks start with information about the environmental and economic benefits of renewable energy technologies (SG-, SD-), 2) scientific principles are then introduced (SG-,SD+), 3) next, engineering principles are presented (SG+,SD+), and 4) practical activities follow (SG+,SD-), although these practical activities tended to have a weaker semantic gravity than required as the task has been overly simplified (represented as SG+↓). No explicit links between the four identified knowledge forms were made, for example, there are no activities that require students to reflect on the scientific or engineering principles underpinning practical tasks. This could be described as one-way traffic from theory to practice, thus no two-way traffic between theory and practice. Cumulative learning requires the application of theory to practice, but also identifying the theory in practice, by critically reflecting on practice. Without cumulative learning there is a tendency to over-simplify and constrain the critical thinking needed to address new problems in new contexts (Waite et al., 2019).

The exit level outcomes do not have the qualities of a vocational subject. For example, most outcome statements use the verb 'explain', which requires scientific or theoretical knowledge – these are outcome with higher levels of semantic density (SD+) and lower levels of semantic gravity (SG-). Very few outcomes contain occupational requirements implied by verbs such as ‘implement’, ‘assemble’, ‘connect’, ‘install’, ‘test’, ‘troubleshoot’, ‘calibrate’, ‘modify’, ‘repair’ or ‘provide assistance’. Thus outcomes with higher levels of semantic gravity (SG+) are largely missing in the subject and assessment guides. Several studies have explained how gaps between academic curricula and the practical requirements of industry negatively impact students’ employability (Durrans et al., 2020; Fitch-Roy, 2013; Kandpal & Broman, 2014; Lucas et al., 2018). The under-representation of practical knowledge in the RET subjects makes it unlikely that graduates will acquire the ‘trade-specific skills, knowledge, values and attitudes’ required for ‘job placements in the green economy’ (RET-SG 4, 2017).

There is considerable repetition across the RET exit level outcomes. Each RET level comprises four topics (see Table 3 above). Topic 1 covers policy and economics at different levels. Topic 2 covers concepts in basic sciences, such as “differences between fossil and renewable energy resources, the sun as the principal source of energy, fundamentals of electricity in direct currents” (RET-SG 2, 2015). These same basic concepts are repeated across all three RET modules. At each level, Topic 3 is a stand-alone item on ‘safety’ with similar content across all three subjects. While safety is particularly important in electrical engineering and renewable energy technologies, it is covered in every subject of the NCV-EIC. In the RET subjects, safety issues need be more specific to the field of renewable energy resources. For example, the Global Wind Organisation (GWO) has established standards for safe practice in the wind turbine industry. In solar energy, safety measures address hidden ground faults, wire sizing, and rapid shutdown, and so on. Topic 4 represents the practical component, such as installation processes for solar water heating systems, wind energy, hydrogen power and fuel cell technology, eMobility and batteries. The wide variety of technologies does not enable a focus on the practical knowledge required for the installation, maintenance and repair of particular technologies. Breadth, rather than depth, in the coverage of renewable energy technologies inevitably results in a weakening of the semantic gravity as the tasks required are necessarily simplified (SG+↓). Thus while there are practical tasks, represented by the plus sign, these have insufficient complexity for the occupational context, represented by the down arrow.

Not only are topic areas repeated across the RET subjects, there is also considerable overlap with other sections of the NCV-EIC curriculum. For example, Topic Area 2 (‘Basic scientific principles and concepts’) at Level 2 repeats much of the key vocational subject content ‘Electrical Principles and Practice’ (Level 2) (see Table 6).

Table 6: *An example of repetition across the curriculum*

Electrical Principles and Practice (2)	**Renewable Energy Technologies (2)**
Explain the concept of electricity and its base values. Build simple DC circuits and perform calculations	Explain the concept of electricity and its base values. Build simple DC circuits and perform calculations.

While outcomes specific to renewable energy, such as “explain energy concepts and investigate energy efficiency options”, are appropriate, the repetition across the RET subjects seems largely unnecessary and potentially demotivating. RET 4 states that it is necessary to repeat key concepts across levels (RET-SG 4, 2017, p. 2), but there does seem to be excessive repetition, which is associated with student demotivation and attrition (Johansson, 2020).

Finding 2: The curricular level

In this section we determined the curricular level by focussing on a practical exit level outcome. The NQF level 4 RET subject was chosen for in-depth analysis as its outcomes could be expected to approximate to standards of practice in industry; in fact, the level 4 assessment guide claims that “emphasis is placed on practical activities and the use of training kits or industrial components” (RET-AG 4, 2017). The RET Level 4 curriculum has a focus on wind energy; in this section the focus is on the learning outcomes and assessment standard of exit level 34 (Table 7).

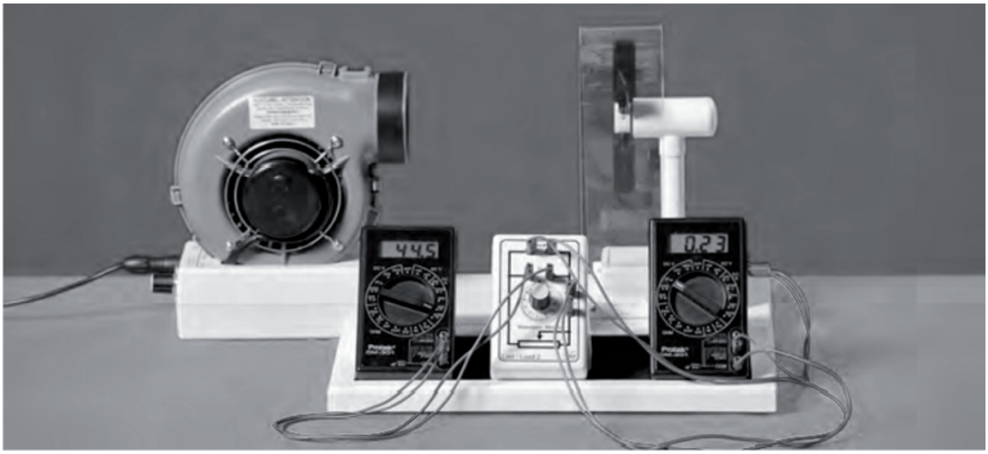
Table 7: *Learning outcomes and assessment standards for exit level outcome 34*

Connect wind turbine components using didactical training kits or small-scale industrial components (34)	
Learning outcomes	**Assessment standard**
1. Identify training kit components or small-scale industrial components. 2. Measure wind speed in the environment. 3. Measure wind speed using a wind machine. 4. Determine output power of a generator depending on blade shape, on the number of blades and blade position. 5. Record the V/I characteristic line of a generator at a constant number of revolutions. 6. Record the V/I characteristic line of the generator on the resistor with drive rotor at constant wind speed. 7. Determine the output power of a generator at different wind speeds. 8. Charge an accumulator using a wind generator. 9. Set an isolated network up. 10. Perform testing and fault finding on all of the above set-ups. If available perform testing and fault finding on installed small-scale installations and, hypothetical in context of large scale installations.	1. Training kit components or small-scale industrial components are identified and the general experimental set-up is established. 2. Wind speed in the environment is measured and results documented in a table. 3. Wind speed is measured using a wind machine at various settings and the results documented in a table. 4. Output power of a generator is determined depending on blade shape (straight, curved), number of blades (2, 3 or 4) and blade position. The results documented in tables. 5. The V/I line of a generator at a constant number of revolutions is recorded and the results documented in a table. 6. The V/I line of the generator on the resistor with drive rotor at constant wind speed is recorded. 7. Output power of a generator at different wind speeds is determined. 8. An accumulator is charged using a wind generator. 9. An isolated network is set up. 10. Testing and fault finding on all of the above set-ups is performed. In addition also on installed small-scale installations and, hypothetical in context of large scale installations.

Learning outcomes	Assessment standard
11. Reflect on the installation, commissioning and servicing of electrical equipment and cabling on turbines, transformers and substations, high voltage switchgear and erection of high and low tension power lines.	11. Relevant aspects regarding installation, commissioning and servicing of electrical equipment and cabling on turbines, transformers and substations, high voltage switchgear and erection of high and low tension power lines are explained. (Range: Medium and high voltage switchgear, transformers, cables, bus bars etc.)

The learning outcomes and assessment standards are intended to guide and assess students' practice (RET-AG 4, 2017, pp. 16-17). The practical orientation of the learning outcomes is evident in terms such as 'measure', 'record', 'charge', 'set-up', and 'perform testing and fault-finding'. These more practically oriented verbs indicate that the semantic gravity will be stronger (SG+). However, students carry out the tasks on an extremely simplified device (Figure 3), which is useful for reinforcing basic scientific and engineering knowledge but does not approximate to practice. The use of the simplified device results reduces semantic gravity (SG+↓), or contextual complexity, indicated by the down arrow in the annotation. Learning outcome 32.11 requires students to reflect on "the installation, commissioning and servicing of electrical equipment and cabling on turbines, transformers and substations, high voltage switchgear and erection of high and low tension power lines". This reflection will not be possible as all that students are expected to accomplish are tasks with a training kit.

Figure 3: *The IKS WindTrainer junior set with some assembled components. Source: Renewable Energies Technologies Textbook, Level 4, p. 137*



No outcomes relate to the specific functions that wind turbine technicians perform. Performing tasks on a simple kit is not adequate preparation for a wind turbine technician. While the simple kit involves practical work, the semantic gravity is not equivalent to that of an actual or more closely simulated training turbine. Wind turbine technicians need to know how to use safety harnesses while using a variety of hand and power tools to do their work. They also use computers to diagnose electrical malfunctions. Most turbine monitoring equipment is located in the nacelle, which can be accessed both on site and off. The Assessment Guide recommends that “visits to local wind farms or single turbine installations are arranged to experience the setup and connections to the grid” (RET-AG 4, p. 17). While site visits are useful and will increase the semantic gravity, site visits are not enough – more hands-on experience is necessary.

The assessment criteria restate the topic area content, sometimes even repeating the same sentence phrasing. For example, the outcome: “Determine the output power of a generator at different wind speeds” is re-stated in the assessment criteria: “Output power of a generator at different wind speeds is determined”. When assessment standards repeat the learning outcomes there is no indication of the performance level required, thus that students might not be developing necessary skills. Assessment in vocational education usually requires students to demonstrate or apply what they have learned in ways that are relevant to the occupation (Billett, 2018). The repetition of the outcome in the assessment criterion suggests a misunderstanding of assessment standards. Conflation results in 1) a lack of clarity with regard to the expected performance; 2) this can also lead to unfair assessment practice (due to the lack of clarity and reduced validity and reliability); 3) as a result, feedback is likely to inconsistent; and 4) for students conflation can lead to a lack of focus, and a shift from learning and skill development to merely achieving the desired outcome, leading to a ‘teaching to the test’ mentality. When outcomes and criteria are conflated, the design of assessment tools and rubrics are less effective. Clear assessment criteria are necessary for creating valid and reliable assessment instruments. In the case of the RET modules, clear assessment criteria would specify the level of performance required, that is the strength of the semantic gravity, as well as the level of scientific knowledge, or the strength of the semantic density. To avoid these consequences, it is essential to establish and communicate clear assessment criteria that align with appropriate outcomes.

Reflections and conclusion

The study addressed the research question: ‘What forms of knowledge underpin the RET curricula, and what is the relationship between these knowledge forms?’ The study found that scientific and engineering knowledge, that have stronger semantic density (SD+) was generally well represented. Generic knowledge was over-represented. The study found that practical knowledge was under-represented, and the level of practical work required by learning outcomes was far off the occupational standard. Practical knowledge building through strengthening the semantic gravity (SG+↑) with appropriate practical tasks was largely missing, creating an imbalance in the curriculum. The relationships between the different knowledge forms was not made explicit. Across the RET guides and textbooks, learning outcomes and assessment standards were conflated. This conflation resulted in lack of clarity with regard to the level and standard of performance required. The level of over-specification in the RET guides suggested a mechanistic approach as well as a misunderstanding of what a curriculum is and what appropriate assessment requires. Lists of outcomes and standards replaced the curriculum, leading to fragmentation, inflexibility, and over-simplification, exacerbated by excessive repetition. We drew on semantic gravity and semantic density to analyse the knowledge forms that underpin curricular outcomes and the relationship between knowledge types. This analysis is the basis of our claim that the RET subjects do not prepare students adequately for entry into occupations in renewable energy.

Changes are needed to include meaningful practical knowledge in the curriculum. A curriculum mapping exercise could highlight key concepts (some of which may benefit from repetition) and clarify knowledge and skills progression across the curriculum. The under-representation of practical outcomes should be addressed, in particular work-oriented tasks that would better prepare students for employment in the green economy.

Successful practical work requires flexible and up-to-date approaches, committed and skilled teachers, engaged students, and the involvement of industry partners in the organisation and facilitation of practical activities – as well as the commitment of educational leaders (Atkinson, 2016). The provision of RET in colleges is unlikely to be successful without multi-institutional involvement and commitment. The involvement of appropriate stakeholders would help educators to develop tasks more appropriate to the field of renewable energy technologies, thereby strengthening the semantic gravity across the curriculum and enhancing the potential for the RET subjects to be relevant and to prepare students for work placements and employment. Currently, addressing the inadequacies of the curriculum relies on dedicated lecturers committed to sustainable energies to go beyond the curriculum.

The knowledge contribution of this study is related to understanding the relationship between the theoretical and practical knowledge forms in a technical curriculum. For cumulative learning to take place, the curriculum should not only include conceptual, applied, practical and generic knowledge, but include iterations across the knowledge forms. In other words, more explicit links between the knowledge forms should be included in an appropriate practical task. A strong vocational curriculum might start with scientific knowledge, or weaker gravity and stronger density (SG-,SD+); the introduction of related engineering principles (SG+,SD+) would strengthen the semantic gravity (SG+,SD+), while introducing practical tasks at the appropriate level would further strengthen the semantic gravity, and weaken the semantic density (SG+↑,SD-) to enable a focus on the complexity of the task in context. However, writing a report and reflecting on the task, enables cumulative learning by connecting the different knowledge forms. Writing a report on practical activity (or engaging in another form of debriefing) could assist students to understand how engineering principles underpinned the procedures. Similarly, providing students with opportunities to reflect on an practical task, would help them to link the scientific principle with the performance of a device. While the outcomes might be listed separately in an official documents, considerably more guidance is required to enable vocational educators to construct a curriculum that has appropriate levels and forms of semantic gravity and semantic density, and in which the different knowledge forms are related. Building RET knowledge and competence requires conceptualising, understanding the engineering problem, the logic of the procedures, and learning in the context of practice. It requires reflection on practice from the viewpoints provided by the different knowledge systems, including that of RET practice. Such curriculum change will pave the way towards a brighter future for South Africa including the students undertaking RET studies.

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Percentage contribution

Areas of contribution	Author	% Contribution per area, per author (each area = 100%)
Conception or design of the paper, theory or key argument	Winberg	50%
	Hollis-Turner	50%
Data collection	Winberg	50%
	Hollis-Turner	50%
Analysis and interpretation	Winberg	50%
	Hollis-Turner	50%
Drafting the paper	Winberg	50%
	Hollis-Turner	50%
Critical review of paper	Winberg	50%
	Hollis-Turner	50%

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Endnotes

1 Note that Maton (2014) reverses the standard positioning of the Y-axis to represent the 'downward pull' of gravity. The semantic plane is not intended to be a mathematical representation.

2 The subject outcomes are referred to by exit level and subject level, thus outcome 30.2 is learning outcome 2 of exit level outcome 30.