

Art. #2209, 10 pages, <https://doi.org/10.15700/saje.v43n2a2209>

## Curriculum integration of physical sciences, engineering science, technology subjects in relation to the technical sciences curriculum

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The aim with this study was to analyse and explore how physical sciences, engineering science and technology subjects (technical electrical technology, technical civil technology, technical mechanical technology) can contribute to the alignment of the technical sciences curriculum. We used document analysis to collect data. An analysis of the curriculum and assessment policy statements (CAPS) for technical sciences, physical sciences, electrical technology, civil technology, mechanical technology, and textbooks for engineering science was done. The findings of the study suggest that the technical science curriculum is a replica of the physical science curriculum. We recommend that the technical sciences curriculum be reviewed such that relevant scientific concepts can be used to bridge the gaps identified in the curriculum. The implications are that a new, aligned technical sciences curriculum that is relevant for technology subjects must be developed.

**Keywords:** curriculum alignment; physical sciences; technical sciences; technology subjects; transdisciplinary integrated curriculum

### Introduction

Technical sciences is regarded as a new subject in South Africa and there is currently a lack of research to improve the standards and identify the challenges and gaps found in the curriculum. The curriculum is always the first to be blamed when the educational outcomes do not meet the needs of society. Alonso Sáez and Berasategi Sancho (2017) argue that major changes in new curriculums are difficult to identify and suggest that any curriculum innovation should be ahead of existing practices, be purposeful and considerate to the ability to change. Eilks and Hofstein (2017) state that the goals and related objectives for science teaching and learning have undergone several changes, often leading to reforms in the teaching and learning of science, technology, engineering and mathematics (STEM) subjects, including technical sciences as a new subject in South Africa. Comparing the curriculums and demands of STEM subjects could provide a standard of reference for new subjects (technical sciences in this case) and educational reforms. Consequently, the weaknesses and strengths of the technical sciences curriculum in relation to the other STEM or integrated subjects were examined because of the limited research currently available on the technical sciences curriculum.

The South African Department of Basic Education (DBE) strives to provide education that is comparable in quality, credibility and efficiency to that of other countries. In trying to provide better education, the subject, technical sciences, was introduced in technical high schools to complement technology subjects in terms of scientific theory. The intention was to allow learners who take technology subjects to be able to integrate scientific knowledge in their subject offerings in a more informed way. Technical sciences was moreover introduced to make scientific concepts and skills more accessible to learners who have a technical orientation in their schooling. Furthermore, the subject was introduced to meet the needs of the industry and technical trade subjects (DBE, Republic of South Africa [RSA], 2014d). The *Technical Sciences Curriculum and Assessment Policy Statement* (DBE, RSA, 2014d) was introduced in South Africa in 2014 in response to a lack of scientific theory and the identification of a content gap for learners majoring in technology subjects. Technical sciences was then introduced as an enabler subject to complement technology subjects in the Further Education and Training (FET) phase of technical secondary schools. Consequently, a quick random solution was applied, where the physical sciences curriculum (DBE, RSA, 2011:8) seemed to have been used as a replica curriculum for technical sciences (DBE, RSA, 2014d:9).

Technology subjects are designed for learners who have a special interest in the practical fields of business and industry. The subjects are designed for learners who strive to enter employment in the nature of work for which they have a direct practical value. Learners are guided to choose technology subjects that they can specialise in secondary school in preparation for their admission to a trade or to the industry. This enables the learners to develop the technical and theoretical knowledge, as well as the workplace knowledge and skills required in their chosen occupational/vocational area, and to be productive in the field of business or industry at entry level. The existence of these subjects is to allow learners to develop an appreciation for good design and to instil good working habits, basic skills and the knowledge associated with the type of work they are expected to do when they enter the industry after secondary school. Technology subjects are designed to encourage an understanding of scientific theory and logical thinking, hence the exploration of the technical sciences curriculum in this study (Ontario Department of Education, 2017).

The literature reviewed suggests that there is a lack of research on the technical sciences curriculum, specifically research on how the technical sciences curriculum conforms to the scientific theory of trade subjects. Research on the technical sciences curriculum was neglected and, consequently, learners struggle with the content because of a lack of connection between technical sciences and what the learners do in technology subjects in practice. Hence, with this study we explored the relevance of the technical sciences curriculum and its alignment to the curriculums of the technology subjects.

We attempted to qualify technical sciences as an enabler subject for technology subjects in technical high schools. Therefore, we analysed five existing curriculums, that is, the curriculums for physical sciences, technical sciences, and the curriculums of three technology subjects. We specifically focussed on the alignment of the curriculums of technical sciences and three technology subjects, electrical technology (ET), civil technology (CT) and mechanical technology (MT). In addition, the relevance of the content of the textbooks for engineering science to technical sciences was explored.

The aim of the study was to analyse and explore how the physical sciences, ET, CT, MT and engineering science curriculums can contribute to the alignment of the technical sciences curriculum. Therefore, we explored the following question: How do the physical sciences, engineering science and technology subjects' curriculums compare with the technical sciences curriculum in relation to the scientific theory of each technology subject?

#### Literature Review

Based on the literature reviewed, there is a lack of research on the technical sciences curriculum, also on how this curriculum should be developed, and what the curriculum should entail to ensure relevance. South Africa's Council for Quality Assurance in General and Further Education and Training (Umalusi) conducted several extensive evaluations related to the transformation of the education system. Matshoba, Burroughs, Arends, De Bruin, Naidoo, Sipholi and Zulu (2013) drew a comparison between old and new curriculums of subjects offered at the Technical and Vocational Education and Training (TVET) colleges. An important part of the research was to gain insight into the relationship between the three levels of the National Certificate Vocational (NCV) and the National Accredited Technical Education Diploma (NATED)/N-level programmes. Among the N-level programmes, engineering science remained an important component of engineering studies because it provided learners access to theory of science, which was needed for the practical engineering subjects. Similarly, the content of the technical

sciences curriculum in comparison to STEM or integrated subjects (physical sciences and technology) was analysed to gain insight into the relationship between these subjects and technical sciences. The study by Matshoba et al. (2013) implies that technical sciences, like engineering science, must play an essential supportive role because it provides the necessary underpinning theory for technology subjects. Therefore, a theoretical component is needed for technology subjects to provide learners with the opportunity to integrate knowledge with practical skills.

According to the Ontario Department of Education (2017), instruction in technical subjects should be supplemented by instruction in related mathematics and science content, the purpose of which is to give a general technical background for the interrelationship between specialised subjects related to the different trades. The content of the interrelated subjects was stressed to realise the techniques of the trade and their dependence on scientific theory. Three main streams were considered in the South African technology subjects namely, mechanical technology (MT), electrical technology (ET) and civil technology (CT). Technical sciences and physical sciences are two of the important major subjects in technical secondary schools, and along with the technical subjects, learners must take either technical sciences or physical sciences (DBE, RSA, 2014d).

The value of a curriculum is based on its being relevant, current and responsive to the skills needed in the industry. A detailed explanation of the development of technology subjects and programmes is attached as Section 2 of the curriculum documents (DBE, RSA, 2014a, 2014b, 2014c:8–12). Yilmaz and Oner Sunkur (2021) studied document analysis and consistency in the curriculum, and they point to the value of consistency or alignment between the components of a curriculum and the content. Curriculum alignment in this study referred to relevancy, efficiency, and applicability of the content in relation to the practical skills, trade work, technology, and the world. Additionally, Yilmaz and Oner Sunkur express that document analysis of technical sciences can assist in providing guidelines to ensure an efficient learning process and quality education. Kocakaya and Kotluk (2016) further indicate that the content of the curriculum, that is, what learners are supposed to know and learn, is defined as educational standards. According to Rorsch (2014), STEM curriculum and integration assist in curriculum reviews and alignment to enhance the quality of teaching and learning outcomes.

Rogan and Grayson (2003) reflect on the theory of curriculum implementation with reference to the improvement of science education and the development of science curriculums. The emerging

theory focuses on the creation of policy documents, placing the emphasis on adoption and neglecting implementation. They indicate that, in nearly all instances, low outcomes resulted from poor implementation of what was essentially an idea. Learners should be active participants in the learning process in order to build a meaningful understanding of concepts that they can apply in their various subjects.

Mpanza (2013) explored the natural sciences curriculum and indicates that teachers were at different levels regarding their ability to implement the curriculum, partly due to the way they interpreted the curriculum. Mpanza (2013) concludes that teachers must be supported in different ways to improve their capacity to implement the curriculum. Mpanza further argues that during implementation, there is always unease, confusion and neglect of the phenomenology of change. She indicates that changes rely on mandates, policy documents, standardised outcomes, direct outside supervision, external assessment and other prescriptive methods. Consequently, changes are likely to be superficial in that they concentrate on visible structures rather than on substance and create a significant gap between what is intended and what is feasible.

As the value of a curriculum is based on it being relevant, current and responsive to the skills needed in the industry, employers need to be central to the development of curriculums since it benefits them through the development of knowledgeable learners who are in touch with current developments and trends in the industry. A detailed explanation of the development of technology subjects and programmes is attached as Section 2 of the curriculum documents (DBE, RSA, 2014a, 2014b, 2014c:8–12).

According to the Department of Higher Education and Training (DHET), RSA (2015), constant changes in technology and production methods have the potential to render the curriculums taught at technical high schools less relevant. The gazette emphasises that curriculums must be reviewed constantly to ensure their alignment to the workplace environment.

Kazlauskienė, Gaucaite and Pocevičienė (2016) reflect on the theory of curriculum implementation and maintain that many schools do not adapt quickly to policy changes. They point out that teachers' professionalism has a greater impact on learning than on curriculum changes and adaptations. Changes in didactics are based on the interaction between theory and practice (in this case, the technical sciences and the technology subject curriculums), which provokes explicit educational strategies or systems and practical implementation that are results oriented.

Wijngaards-de Meij and Merx (2018) argue the importance of curriculum alignment in the

development of the curriculum to enhance learning. They highlight challenges, best practices and methods of enhancing curriculum alignment. They developed a tool to help academic developers facilitate processes of improving curriculum alignment for teaching and learning within different courses that build towards achieving learning objectives.

Ziebell and Clarke (2018) conducted a comparative case study to examine the process of curriculum alignment and how the intended goals of a proposed curriculum were interpreted for planning, instruction and assessment purposes. The results reveal that the intended goals of the proposed curriculum at classroom level were complex and dynamic and needed alignment. The alignment was influenced by the sources, such as standardised testing programmes, textbooks and curriculum consultants. We did a comparative study using different curriculum documents and textbooks of science-related programmes and disciplines.

Li, Zhang, Yuan and Birkeland (2019) engaged in critical document analysis, exploring different curriculum documents by comparing the ways in which different curriculums were conceptualised and how they were sustained. The comparative document analysis showed that predominant cultural dimensions of context, such as individualistic and collectivist factors, shaped the understandings of sustainability of curriculums in each country. They engaged ideas associated with curriculum sustainability and emphasise that a curriculum document should have a vision of competent and confident learners who can make a valuable contribution to society. They indicate that variety and diversity must be respected and embraced within curriculum frameworks since they play an important role in obtaining experts' guidance and mandates for initiatives such as education for sustainability. Key stakeholders in academic policies and professional worlds need to explore concepts and practices that define a dynamic understanding of curriculums and their complications.

Gürkan (2021) scrutinised teachers' experiences using a model by designing a transdisciplinary integrated curriculum framework. It was found that the model was effective and advanced teachers' coping skills and relieved their challenges. The outcomes indicate that teachers' experiences are of significance in terms of the design of integrated programmes. Collaborative work and the ability to meet the requirements of different disciplines with a joint mechanism became evident.

#### Theoretical Framework

In our study we worked within a framework that allows for interdisciplinary and transdisciplinary approaches to integrate the explored curriculums.

We analysed the integrated curriculum documents (physical sciences, engineering science, ET, CT, and MT) to generate scientific concepts that were relevant to align the technical sciences curriculum. The purpose of the study was to find a means to align the technical sciences curriculum using an interdisciplinary framework. The interdisciplinary approach was geared towards finding clearer connection between technical sciences and the technology subjects. The curriculums that we explored were interpreted to account for the integrated relationships and to discover common concept, skills, indistinct borders, and connections between them (Gürkan, 2021).

The interdisciplinarity of knowledge structures in the integrated curriculums were explored to connect scientific concepts to the practical skills learnt in the technology subjects (Pountney & McPhail, 2017). Gürkan (2021) states that the purpose of integrated curriculums is to clarify the concepts related to a situation, or problem, to ensure that learning occurs through a higher level of thinking and to support the formation of different connections between theory and practical skills in preparation for trade work, industry, and the world.

You (2017) describes the history of interdisciplinary education to explain the conceptual framework and its standards in science teaching. Interdisciplinary learning in science is characterised as a perspective that integrates two or more disciplines into coherent connections to enable learners to make relevant connections and to generate meaningful associations. A gap was identified on how the technical sciences curriculum conforms to the scientific theory behind the technical skills learned in technology subjects.

### Research Methodology

Qualitative research in the form of document analysis was carried out to gain a realistic perspective and an understanding of the existing integrated curriculums, namely, the curriculums of physical sciences, engineering science, technical subjects and technical sciences. An interpretivist approach was used to report the relationships uncovered among the different curriculums. A transdisciplinary approach was used to find the point of intersection for the integrated subjects (Gürkan, 2021). In the research we focused on the relevance of the technical sciences curriculum in relation to the curriculum of technology subjects.

We used document analysis for data collection and the CAPS for the following subjects were analysed: technical sciences, physical sciences, technology, as well as the textbooks for engineering science. From the document analysis we found that the engineering science curriculum did not provide content or scientific concepts required to guide teaching and learning in class. The absence of such guidance led to the use of engineering science

textbooks instead of the curriculum document, since the textbooks had the relevant content needed for this research. Engineering science is a NATED course, designed to address the scientific theory related to the trade or practical skills learned at TVET colleges.

Engineering science taught at TVET colleges and technical sciences taught at technical secondary schools are comparatively equivalent subjects. Similarly, engineering subjects (courses) at TVET colleges, and technology subjects in technical high schools, referred to as trade subjects or practical subjects, are also comparatively equivalent. Engineering subjects for the undergraduate qualifications in the TVET colleges, N1, N2 and N3, provide knowledge and skills needed for employment, and involve the use of formal, non-formal and informal learning. NATED courses (N1–N3) have equal corresponding value to the FET Phase (Grades 10–12) in terms of the National Qualifications Framework (NQF) level. An elementary certificate of NQF level 2 is awarded on completion of Grade 10 or N1; an intermediate certificate of NQF level 3 is awarded on completion of Grade 11 or N2; and a National Senior Certificate (NSC) of NQF level 4 is awarded on completion of Grade 12 or N3 (Matshoba et al., 2013).

Scientific concepts referred to in the five curriculum documents were explored. Printed and electronic documents were systematically analysed, interpreted and evaluated. Data were explored and scrutinised to find meaning, to advance understanding and to develop pragmatic knowledge (Dias de Figueiredo, 2018). The physical sciences, engineering science and technical sciences documents were interrelated, and the final product was compared with the main streams of the technology subjects, namely, MT, ET and CT. We started by coding the data for the major categories of the three integrated subjects (technical sciences, physical sciences and engineering sciences) and referred back to the technology main streams. We took a closer look at the scientific concepts of different documents and performed coding and category construction to uncover themes and content relevant to technical sciences. Coding was used to organise and to categorise the data, which served as a way of establishing, gathering and compiling the data. Comparisons were done, and templates were developed to tabulate similarities and differences between the scientific concepts in the explored documents (Creswell & Poth, 2016).

Initial coding was performed and marginal remarks were compiled by comparing scientific concepts in the CAPS of technical sciences and physical sciences. The learning areas of the two subjects were also compared and are discussed under Category 1 of the results. Coding was also done by comparing the scientific concepts in the technical sciences curriculum with the contents in

the engineering science textbooks. A comparison was done per grade per NATED NQF level, and the content was tabulated to derive relevant scientific concepts in Category 2. The applicable scientific concepts were derived to be relevant and applicable to the knowledge areas of the three technology main streams. The textbooks for engineering science were identified for use to explore the relevant scientific concepts since that subject was equivalent to technical sciences. The technology subjects embrace practical skills and the application of scientific principles, and we extracted possible scientific concepts that were relevant to the technology subjects. The Engineering Science textbooks for N1, N2 and N3 were scrutinised to generate matching scientific concepts that were relevant and applicable to technical sciences. The scientific concepts from Categories 1 and 2 were consolidated in Category 3 to generate all the relevant scientific concepts, which were summarised to further compare them to the three technology subjects (mechanical, electrical and civil technology). In the analysis we focused on the content and skill specification of each technology subject to establish scientific concepts that are relevant to the technical sciences curriculum.

The scientific concepts relevant to each technology subject were traced or searched by typing the words scientific concepts in the search window in the electronic CAPS documents. The presence of these words in the CAPS documents confirmed their relevance. Concepts that were not found in the documents were subsequently considered irrelevant and removed for the recommended curriculum. Tables or templates were developed to simplify data for the interpretation and analysis of the results.

A qualitative content analysis of the five curriculum documents provided a means of tracing similarities, variations, deviations and developments. These curriculums were tabulated for comparison of concepts that were common, and those that were not, to obtain a deeper understanding of the usage of concepts. Data were collected qualitatively to recognise, evaluate and explore raw data in order to describe patterns, trends, themes and categories and to interpret the underlying meaning (Ngulube, 2015). Content analysis was used and statements in the curriculum documents were coded and categorised (Engelbrecht, Nel, Smit & Van Deventer, 2016). The coding exercise directed us to prepare a data analysis to ensure reliability and consistency and to reduce individual, interpretive bias (Creswell & Poth, 2016). Consequent to the coding of the scientific concepts in the curriculum documents, an experienced researcher was requested to repeat the process by coding the

concepts independently until a greater reliability of coding was accomplished. Differences in coding were regularly compared, deliberated on and resolved to encounter the level of consistency.

Data were qualitatively analysed and compared to interpret the scientific concepts in the explored curriculum documents. Indicators were used to identify the presence or the absence of scientific concepts in the documents. Through the analysis we needed to discover relationship between the scientific concepts in the integrated curriculums to create a balance between theory and practice for the technical sciences curriculum. The technical sciences curriculum was explored, scrutinised, and interpreted comparatively to generate a technical sciences curriculum that was relevant to the technology subjects.

Three categories were used to explore the content of the different curriculums for the generation of the recommended technical sciences curriculum. In Category 1, technical sciences and physical sciences were compared; in Category 2, concepts in technical sciences and engineering science were also compared to extract the relevant scientific concepts. In Category 3, the scientific concepts were analysed relative to the technology subjects, by reading and coding the data in the first two categories. The scientific concepts from these two categories were then consolidated and further sectioned into learning areas (Bowen, 2009).

### Findings

The descriptive analysis covered the two categories of comparison of the scientific concepts. The frequency of the concepts was checked to find the extent to which the content of compared curriculums differed and the data obtained were analysed.

#### Category 1: Comparison between Physical Sciences and Technical Sciences Curriculum

The combined scientific concepts generated from the comparison of the existing physical sciences and technical sciences curriculums suggest the relevant scientific concepts that should be included in the recommended technical sciences curriculum. The physical sciences curriculum was compared to the technical sciences curriculum and similarities and differences between the scientific concepts were identified. The six main knowledge areas of technical sciences are presented in Column 1 of Table 1, and the six main knowledge areas of physical sciences in Column 2. The roman bold text indicates that the concept appears in technical sciences only and the italicised bold text indicates that the concept appears in physical sciences only; all other concepts appear in both curriculums.

**Table 1** Comparison of technical sciences and physical sciences curriculum

Technical sciences CAPS	Physical sciences CAPS
<ul style="list-style-type: none"> <li>• Matter and materials</li> <li>• Chemical change</li> <li>• Mechanics</li> <li>• Waves, sound and light</li> <li>• Electricity and magnetism</li> <li>• <b>Heat and thermodynamics</b></li> </ul>	<ul style="list-style-type: none"> <li>• Matter and materials</li> <li>• Chemical change</li> <li>• Mechanics</li> <li>• Waves, sound and light</li> <li>• Electricity and magnetism</li> <li>• <i>Chemical systems</i></li> </ul>

Out of the six knowledge areas in the two curriculums, five concepts were similar and appeared in both curriculum documents. Only one scientific concept in each curriculum was different. The concept heat and thermodynamics appears in the technical sciences curriculum only. Similarly, the physical sciences curriculum differs from the technical sciences curriculum because it includes the concept chemical systems, which is not included in the technical sciences curriculum. The purpose of the comparison was to determine the extent to which the two curriculums varied, and the results indicate that similarities were greater than the differences. The differing concepts, identified in bold letters, were checked further in the technology curriculum documents in Category 3 to check their relevance.

**Category 2: Comparison between Engineering Science and Technical Sciences**

The descriptive analysis of this category covered the comparison of the scientific concepts per grade (Grades 10, 11 and 12) and per NATED level (N1, N2 and N3). The comparison was aimed at determining the extent to which the content of the two equivalent subjects varied (cf. Table 2). In the discussion we compared the common and different concepts found in the technical sciences and the engineering science curriculum. These concepts were traced further in the technology CAPS to check their relevance for recommendation in Category 3.

Variations of scientific concepts between the two subjects (cf. Table 2) were coded as the missing concepts; Column 1 representing engineering science, and Column 2 technical sciences. In Column 1, the concepts are captured in normal font, the sub-concepts in italics, and any bolded text is a missing concept, meaning that no matching concepts were found in the technical sciences CAPS documents. Column 2 indicates technical sciences concepts that were found missing in the engineering science textbooks. All other concepts that are not listed in Table 2 were found in both subjects (common concepts) and are listed and discussed in Category 3. Following is the interpretation of the table and the discussion of the engineering science concepts versus technical sciences knowledge areas.

**Table 2** Comparison between technical sciences and engineering science – missing concepts

Engineering science textbooks	Technical sciences CAPS
Engineering science N1 (Van Rensburg, 2019)	Grade 10
<ul style="list-style-type: none"> <li>• Measurements: <i>calculator (programmable calculator, calculating areas of regular and complex shapes, and volume)</i></li> <li>• Statics: <i>lifting machines</i></li> <li>• Heat: <i>linear expansion, heat capacity and specific heat capacity</i></li> </ul> Electricity and magnetism: <i>Ohm's law, heating effects of electric circuits, electric power, cells and magnetism</i>	
Engineering science N2 (Olivier, 2017)	Grade 11
<ul style="list-style-type: none"> <li>• Dynamics: <b>distance, displacement, speed and velocity, acceleration, kinetics where acceleration takes place, horizontal movement</b></li> <li>• Friction: <i>friction angle, laws of friction, advantages and disadvantages of friction, how to increase or decrease friction, coefficient of friction</i></li> <li>• Statics: <i>couples, the turning effects of a force</i></li> <li>• Electricity: <i>resistivity (specific resistance), electromagnetic induction, self-induction and Lenz's law</i></li> <li>• <b>Mass, weight and newton; Work, energy and power; Particle structure of matter; Chemical bond; Energy and momentum; Work, power and efficiency; Mechanical drives and lifting of machines; Hydraulics; Heat.</b></li> </ul>	Waves, sound and light
Engineering science N3 (Van Rensburg, 2016)	Grade 12
<ul style="list-style-type: none"> <li>• Friction: <i>static and kinetic friction</i></li> <li>• Motion, power and energy: <i>belt drives and angle of contact</i></li> <li>• Forces: <i>conditions of equilibrium, analytical resolution of problems on systems of coplanar forces and simple frameworks</i></li> <li>• Chemistry: <i>corrosion</i></li> <li>• Electricity: <i>cells, Joule's law, electric power and transformers</i></li> <li>• <b>Friction; Moments; Heat; Hydraulics</b></li> </ul>	Matter and material  Waves, sound and light

**Grade 10 compared to N1** (Van Rensburg, 2019): In Column 1, the first six concepts of N1 that form part of the knowledge area mechanics in Grade 10 were missing. The other concepts magnetism

under the knowledge area electricity and magnetism and linear expansion under the knowledge area heat and thermodynamics, were also missing. Column 2 under Grade 10 is empty, indicating that all the

concepts in the technical sciences curriculum were found in engineering science textbook, meaning that no missing concepts were identified in Grade 10 technical sciences.

**Grade 11 compared to N2** (Olivier, 2017): In Column 1, the first two concepts under the knowledge area mechanics in Grade 11 were present, but their sub-concepts were missing from Grade 11 technical sciences. Similarly, the concept electricity in engineering science, under the knowledge area electricity and magnetism of technical sciences was also present, but three sub-concepts were missing. The last bullet indicates scientific concepts in engineering science that were missing from technical sciences. In Column 2, the concepts waves, sound and light in technical sciences Grade 11 were missing from engineering science N2.

**Grade 12 compared to N3** (Van Rensburg, 2016): In Column 1; the first three sub-concepts missing from were identified under the knowledge area mechanics in technical sciences. The concept corrosion was also missing in technical sciences but was found, under the knowledge area chemical change in technical science. Four sub-concepts in engineering science under the knowledge area electricity in technical sciences, were also missing. The last bullet shown concepts in engineering science that were missing in Grade 12 technical sciences. Lastly, Column 2 indicates two knowledge areas of technical sciences that do not appear at all in engineering science N3. The purpose of the comparison was to determine the extent to which the content of the two equivalent subjects (technical sciences and engineering science) varied, and the results show that there is a distinct difference between the content of the two equivalent subjects.

The data presented in Tables 1 and 2 were analysed to explore the relevance of the scientific

concepts that need to be added or removed from the existing technical sciences curriculum. The similarities and differences from the two categories suggest the scientific concepts to be considered for the alignment of the technical sciences curriculum. The relevance of the compared scientific concepts from engineering science and technical sciences (first two categories) were further checked against technology main streams (mechanical, electrical and civil technology). The missing concepts were traced in the individual technology subjects, to relate them to the practical skills. The concepts that were found in the technology documents were noted as bearing relevance to the recommended technical sciences curriculum discussed in Category 3.

### Category 3: Technical Sciences Concepts per Learning Area

The analysis of the first two major categories laid the foundation for the alignment of the technical sciences curriculum. In Category 3, the scientific concepts were grouped into four learning areas to be recommended for technical sciences (cf. Table 3). The first learning area, categorised as fundamentals of technology, consolidates scientific concepts that were found in the three technology CAPS documents. Scientific concepts that were found in one technology curriculum document but found missing in the other technology documents were considered relevantly aligned to that particular technology subject as a learning area. The relevance of the scientific concepts was traced and explored against the background of each technology subject, namely, the electrical technology (ET), civil technology (CT) and mechanical technology (MT). Table 3 outlines the scientific concepts per learning area, followed by the interpretation in the next paragraph.

**Table 3** Scientific concepts per technology learning area

Learning area	Scientific concepts
<b>Fundamentals of technology</b> (ET, MT, CT)	Measurements, electricity, work, energy, power and efficiency, heat, matter and material, machines.
<b>Mechanical sciences</b>	Sound and light, material, measurements; work, energy, power and efficiency, machines; mechanical drives, moments, friction, hydraulics, dynamics, electricity, magnetism
<ul style="list-style-type: none"> <li>• Automotive</li> <li>• Welding and metal work</li> <li>• Fitting and machining</li> </ul>	
<b>Electrical sciences</b>	Waves and sound; material, measurements, electricity and magnetism, work, energy, power and efficiency, machines
<ul style="list-style-type: none"> <li>• Electrical (power systems)</li> <li>• Electronics</li> <li>• Digital electronics</li> </ul>	
<b>Civil sciences</b>	Material, measurements, work, energy, power and efficiency, machines, moments, mechanical drives
<ul style="list-style-type: none"> <li>• Civil services</li> <li>• Construction</li> <li>• Woodworking</li> </ul>	

In Category 1, chemical systems, heat and thermodynamics were identified as missing concepts. These concepts were traced in the technology CAPS documents so that they could be placed relevantly in Table 3 or removed from the

table. Heat appeared in all three technology documents (CT, MT and ET) and was placed under fundamental concepts. The concept thermodynamics was absent in the three technology documents and was removed from the table. The

same procedure was followed with the concept waves, sound and light. The results show that the three concepts were absent from CT, therefore they were removed from CT concepts; while in ET, wave and sound appeared while light was removed; and in MT, sound and light appeared, while waves was removed. All concepts that were found in any of the technology subjects from Category 1 were relevantly placed in Table 3.

In Category 2, concepts that were missing in engineering science outnumbered those that were missing from technical sciences. Therefore, interpretation started with the missing concepts in the technical sciences document. Two main concepts were found missing – the first was waves, sound and light, which is discussed in the paragraph above. The second was matter and materials, which appear in the three technology CAPS documents and was therefore added as a fundamental concept to Table 3.

Thirteen concepts missing from engineering science in Category 2 were missing from N1, N2 and N3 (sub-concepts italicised) as follows; heat, matter, measurements, dynamics (*distance, displacement, speed and velocity, acceleration, kinetics*), statics (*lifting machines*), moments, friction, work, power and efficiency, energy and momentum, mechanical drives and lifting of machines, electricity and magnetism and hydraulics. Of the 13 concepts, heat and matter had already been discussed and were ignored, while others were checked for relevance.

The following are concepts that were found in the three technology documents (CT, MT and ET) and were added under fundamentals of technology in Table 3: measurements, electricity, work, energy, power and efficiency. Machines were also added to the first learning area in Table 3 because it also appeared in the three technology documents. The sub-concepts under dynamics (italicised in the paragraph above) were traced and only found in MT; the sub-concepts under statistics were also traced and found in MT together with friction and hydraulics. Electricity and magnetism, sound and material appeared in MT and ET, and did not appear in CT. Moments and mechanical drives were only found in MT and CT, but not in ET.

The only concepts that were found missing in the three technology documents were momentum from Category 2, thermodynamics from Category 1, and both were removed from Table 3. The missing concepts that were found relevant were consolidated to develop a list of concepts to be recommend for the technical sciences curriculum (cf. Table 3).

## Discussion

Comparisons were drawn to show similarities and differences between the scientific concepts in the explored documents (i.e., the technical sciences and physical sciences curriculums and engineering science textbooks) to maintain a balance between

theory and practice and recommend for technical sciences. The subjects explored are individual subjects that are integrated and have similarities that demonstrate interdisciplinary and transdisciplinary crossroad (Frickel, Albert & Prainsack, 2016).

When the knowledge areas for technical sciences and physical sciences were compared in Category 1, the results indicate that most of the concepts in the technical sciences and physical sciences curriculums were similar, and only one difference appeared in each subject (cf. Table 1). The results suggest that the technical science curriculum is a replica of the physical science curriculum. Frickel et al. (2016) suggested a transdisciplinary crossroad to produce the relevant curriculum. This will assist in aligning the curriculum to avoid repetition (Ziebell & Clarke, 2018). The approach adopted in our study showed the connections between physical sciences and technical sciences, and at the same time, drawing lines that cut across subject matter in the two subjects.

Category 2 entailed a further comparison to illustrate similarities and differences between two equivalent subjects (technical sciences and engineering science). The results in this category reveal that the two equivalent curriculums were significantly different in respect of the number of missing concepts. The results show that the concepts that were absent and yet relevant were related and aligned to the technology subjects. Barton (2019) and the Ontario Department of Education (2017) support the integration of science and technology subjects because of the relevance and the understanding of the scientific theory in relation to practical skills.

In Category 3 of this study we generated scientific concepts from the explored curriculums, after the results suggested that the integrated subjects had overlapping and aligned elements that were relevant for a technical sciences curriculum. The findings of this study imply that technical sciences, like engineering science does not play an essential supportive role to provide the necessary underpinning theory for the technology subjects, as emphasised by Matshoba et al. (2013). The results of this study confirm that the generated technical sciences curriculum had connections with the technology subjects. Technical sciences fulfils a distinctly different role than that of the technology subjects because it makes provision for science theory and practice (DHET, RSA, 2015).

Unexpected gaps were also identified in our analysis where knowledge progression was not found among grades. It was found that certain concepts did not progress throughout the grades in the technical sciences curriculum. For example, matter and material appeared in the Grade 10 and 12 curriculums, but not in Grade 11. It was evident that progression of knowledge, as tested and supported

by Jin, Shin, Johnson, Kim and Anderson (2015), had not been considered.

An identified gap suggests that further research be conducted on the progression of knowledge and the spreading of concepts across the grades (from Grade 10 to Grade 11 to Grade 12) to ensure conceptual development (Pexman, 2019). The examples identified in this study indicate gaps that prompt further research on sequencing and progression of knowledge for conceptual development (DHET, RSA, 2015).

### Conclusion

The interdisciplinarity links between physical science, engineering science and technology subjects were harmonised into a coherent whole to align the technical science curriculum, such that it is relevant to enable the understanding of the scientific theory behind practical skills learned in the trades. It is recommended that the technical science curriculum be modified to allow scientific theory to merge with practical skills in the technology subjects. With this research we were unable to detect the distinctiveness of the technical sciences curriculum and detected a replication of the physical science curriculum. We suggest that the technical sciences curriculum be reviewed, such that relevant scientific concepts can be used to bridge the gaps identified in the curriculum. It is recommended that the technical sciences curriculum (Grades 10–12) be derived from engineering science subjects (N1 to N3) in terms of the content. It is recommended that the technical sciences curriculum be reviewed, such that it is relevant to enable an understanding of the scientific theory behind the technology subjects taught in technical high schools. Further research is required to investigate progression of knowledge in the technical sciences curriculum for conceptual development.

To develop a properly aligned curriculum that is relevant for the technology subjects, we further propose that an equivalent existing trade subject in the TVET colleges be used to guide the development of a relevant technical sciences curriculum. We believe that if the subject with an equivalent qualification value (REQV) was used to develop the technical sciences curriculum, there would not have been an impression that the existing technical sciences curriculum was a replica of the physical sciences curriculum. In trying to align the technical sciences curriculum, we suggest that the scientific concepts found in engineering science textbooks (equivalent subject) be used to guide the development of the curriculum for technical sciences.

### Authors' Contributions

ATM mentored the researcher and guided the research, reviewed the final manuscript, and constantly critiqued the writing process. MJM

conceptualised the paper, analysed the data and prepared the manuscript. Both authors read and approved the final manuscript.

### Notes

- i. Published under a Creative Commons Attribution Licence.
- ii. DATES: Received: 20 May 2021; Revised: 24 April 2022; Accepted: 8 November 2022; Published: 31 May 2023.

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