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TWENTY YEARS INTO THE NEW MILLENNIUM: HOW INTEGRATED IS MATHEMATICS, PHYSICS AND COMPUTER SCIENCE AT SECONDARY SCHOOL LEVEL?

ABSTRACT

Twenty years into the millennium, the world has been confronted with a pandemic that has had an immeasurable impact on the workplace, learning environment and related technologies. Technology and technological advancements are founded on three disciplines, namely Physics, Mathematics and Computer Science. Internationally, an integration of the curricula of these disciplines are promoted in the education space, as an effective way to achieve 21st century capabilities that lately includes computational thinking. This study explores the changes in the content and alignment of the three subjects in the South African secondary school system from an interdisciplinary framework perspective. Textbooks, curriculum documents and planning calendars provided the information for the content analysis. The content in Physics and Mathematics have remained basically the same, with a few topics removed from Physics and some added to Mathematics. Information Technology has replaced Computer Science, with significant changes in content in alignment with developments in computing technology. No clear indication of an alignment between the disciplines could be found, which, to a certain extent, puts South Africa outside the international frame. The basic education system appears to run an assessment-driven curriculum in Mathematics, Physical Sciences and Information Technology. This system produces poor results and seemingly does not allow for interdisciplinary skills development.

Keywords: *Physics and Mathematics education, computing integration, curriculum alignment, FET phase.*

1. INTRODUCTION

Science, Technology, Engineering and Mathematics (STEM), as a collective framework, focuses on issues and explores epistemological questions on generic skills and the curriculum structure that would support or underpin interdisciplinarity (Millar, 2020). To date, however, there seems to be real difficulties with such curricula, including issues about theoretical frameworks, specified content knowledge and multiple interpretations of what the acronym

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actually represents (Martín-Páez *et al*., 2019). One example is from Wells (2019), who emphasised that the STEM acronym does not promote solidarity but perpetuates the traditional approaches to the individual disciplines comprising this grouping. He specifically pointed to the "T" in STEM, opining that, since inception, it was understood to be represented by a discipline in itself, aiming at technological literacy for all and not just instructional technologies, as commonly reported on by STEM researchers. The acronym has even been extended to STEAM with the inclusion of the Arts in Korea (Drake & Reid, 2018).

Moving away from STEM as being a grouping of separate subjects or merely a collective name, it is instead increasingly seen as a solution for a range of purposes and directed by a discourse of interdisciplinarity, common or generic skills development and lately the employability of a person (Millar, 2020). When thinking about developing integrated skills and preparing for the world of work, the digital nature of study and work came to the fore. The two decades prior and the two following the advent of the new millennium, took us through developments and events that had major impacts on the learning and working environments (Figure 1). By 1980 we have seen the birth of modern computing, with the production of the world's first commercial microprocessor, the Intel 4004 (Guadin, 2011). It caused a digital revolution that resulted in a multitude of new applications such as the pocket calculator, the home or personal computer (PC), new operating systems, programming languages, as well as the founding of internetworking.

The next twenty years, leading to the year 2000 (Y2K), saw the introduction of a multitude of applications, including fax machines, cell phones, laptops and the World Wide Web (WWW). Y2K ignited commercial and technical activities due to the fear of the impact that the digits, "2000", could have had on computing systems all over the world (Uenuma, 2019). By 2020, we all knew of cloud computing (Griffith, 2020), the internet of things (Evans, 2011) and a new industrial revolution (Schwab, 2015). The work environment and the learning landscape became digital and increasingly complex, which has been further fuelled by the COVID-19 (C19) pandemic.

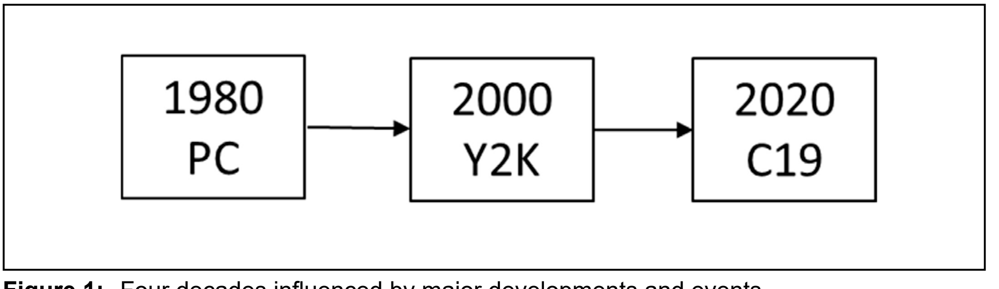

Figure 1: Four decades influenced by major developments and events.

Computing developed rapidly over four decades and the fields of Computer Science and Information Technology matured. Although computational thinking (CT) received increased attention as a basic skill (Wing, 2006; Nouri *et al*., 2020) and STEM research has grown substantially over the past two decades, we have not seen the inclusion of Computer Science or Information Technology in the STEM grouping. Lately, there have at least been endeavours to integrate CT, specifically into K-12 STEM education, as illustrated by a recent special issue of the *Journal of Science Education and Technology* (Lee *et al*., 2020).

The focus of the international push towards STEM education in recent years has been on the curriculum being interdisciplinary, but it has different implications at the various education levels (Millar, 2020). Secondary schooling as the gateway to employment and further education has been selected as the level of attention for the purpose of this paper. In South Africa the Further Education and Training (FET) phase is specifically important as it represents the final three years of formal schooling (grades 10 to 12). It seems as if STEM refers to collectiveness rather than integration locally (Kahn, 2013; Tikly *et al*., 2018). FET content, alignment and possible integration will be probed in this paper to comment on preparedness for the post school environment.

2. CONCEPTUAL FRAMING

Three disciplines, Physics, Mathematics and Computer Science, constitute the base of the technological advancements that we experienced during the 1980–2020 era. By 1980, Computer Science was established as a discipline for university and technical studies and as an additional subject at the secondary school level. Typical of the time, the three disciplines, Physics, Mathematics and Computer Science, existed independently (Figure 2), with some interaction among scholars and practitioners in these fields. This was particularly notable when curricula were designed to teach school learners and university students for studies in these disciplines and to prepare them for the work environment.

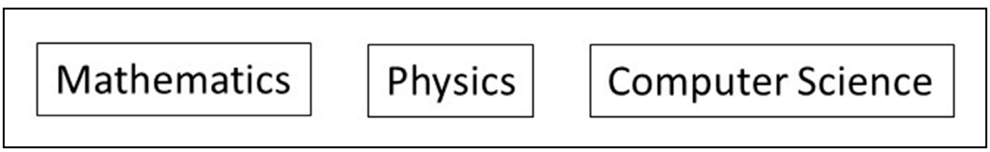

Figure 2: Mathematics, Physics and Computer Science presented as independent disciplines at the university and secondary school levels

During the twenty years leading to Y2K, physicists and mathematicians teaching mainly at the university level, realised the shortcomings and challenges confronting students when studying in these areas. We experienced an exponential growth in Physics and Mathematics educational research (PER-Central, 2021) that contributed to our understanding of how students could learn better and how curricula could be structured to facilitate improved learning (Van den Akker, 2004). Experiences and ideas developed that Mathematics and Physics (or science) could be presented as part of a continuum (Figure 3), as opposed to stand-alone subjects (Figure 2).

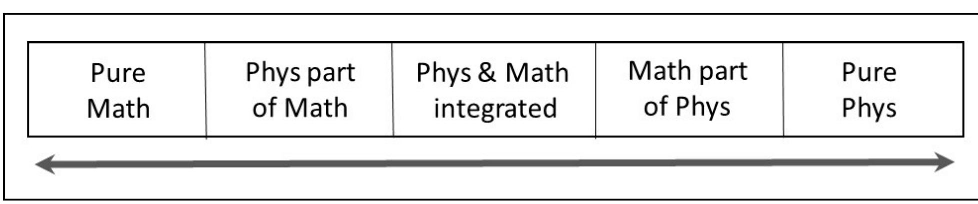

Figure 3: Illustration of the Mathematics–Physics integration continuum (Basson, 2002)

Interaction improved between Mathematics and Physics educators, but this did not extend to Computer Science educators, although the Association for Computing Machinery's (ACM) Special Interest Group on Computer Science Education have been in existence for more than 50 years (SIGCSE, 2021). Examples of the integration of Mathematics and Physics with Computer Science are limited, with exceptions mostly found in very specific courses designed to provide certain pedagogical benefits. An example of such a course is presented by Pruski and Friedman (2014), who reported on a course for first level students, where they integrated calculus-based Physics with Computing using mathematical modelling. The objective was for seamless integration of the three areas: the course should neither be a Mathematics course, with components of Physics and Computing, nor a Physics or Computing one, with elements of the other two. They used MATLAB as the computing environment and introduced some basic concepts of computer programming. The course did not replace existing courses in any of the disciplines. It was aimed at developing critical thinking and enhancing conceptual understanding, while also providing experiences that illustrated that the subjects are not separate and disjointed entities.

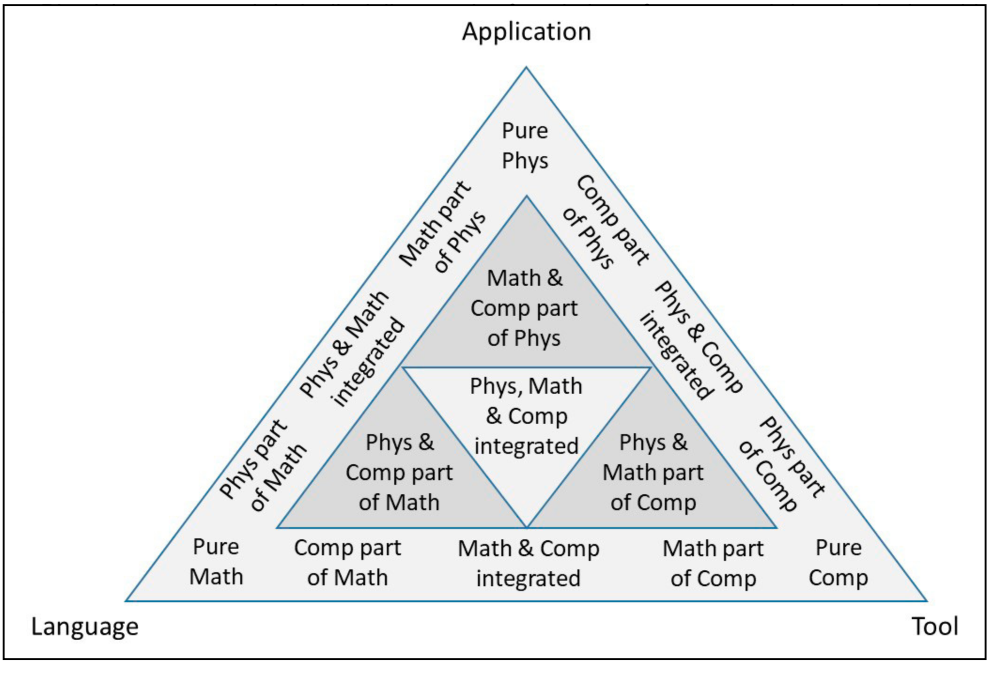

Figure 4: Complexity of a Physics-Mathematics-Computer Science teaching/learning landscape.

3. FRAMEWORKS

There are various ways or forms to represent curricula (Van den Akker, 2004). Curriculum development and planning encompasses various levels. In curriculum design a distinction is made between the macro (system/society/nation), meso (school/institution), micro (classroom) and nano (individual/personal) levels. Van den Akker (2004) opines that a distinction should be made between curricula as "intended" (ideal, formal), "implemented" (perceived, operational) and "attained" (experiential, learned). For this paper, the focus will be on the macro and micro levels, in conjunction with the intended and implemented forms associated with the curriculum. In South Africa, we identify the macro level as the National Department of Basic Education (DBE), with the current Curriculum and Assessment Policy Statement (DBE, 2011) as the intended curriculum. At the micro level, the focus is on the implemented curriculum, here represented by the content presented in textbooks and in the annual planning documents forwarded from national or provincial levels to teachers for classroom implementation.

Emphasising the development of 21st century capabilities and an integrated curriculum as an effective way of achieving these capabilities, Drake and Reid (2018) offered a continuum for constructing such a curriculum. The span includes transdisciplinary, interdisciplinary, multidisciplinary and fusion as ways for integration. They proposed the Know, Do, Be (KDB) framework for constructing an integrated curricula. “Know” takes the focus away from memorising facts to conceptual thinking, “Do” shifts from lower-order skills to more complex interdisciplinary capabilities such as critical thinking, and “Be” adds character building that includes aspects such as mental health, values and attitudes.

Michelsen (2015) proposed a didactical framework for interdisciplinary teaching between Mathematics and Physics, based on two aspects. The first is a didactical model for coordination and interaction between Mathematics and Natural Science subjects, consisting of two phases. The model starts with a phase of horizontal linking, when concepts and process skills from the two disciplines are connected by thematic integration, utilising modelling activities. Next, conceptual anchoring of the concepts that constitute a vertical structuring phase. This phase allows learners to move about analytically and logically within Mathematics and the Natural Science subject(s) in the interacting or an interdisciplinary context. The second aspect of the framework is the conception of modelling as an interdisciplinary competency. It stems from an interpretation that modelling is a Mathematics as well as a Science competence: “competency development can be seen as a lynchpin for interdisciplinary activities” (Michelsen, 2015: 493). Here, computing could be included based on modelling as a vehicle for development of skills.

In addition to the above, Weintrop *et al*. (2016) proposed a taxonomy comprising four categories as a possible definition of CT for Science and Mathematics. The taxonomy describes the categories as “practices as opposed to skills or concepts in order to emphasise that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice” (Weintrop *et al*., 2016: 134). The four categories are data, modelling and simulation, computational problem solving and systems thinking practices, with each category consisting of five to seven CT subsets.

An overview of the frameworks is provided to offer a window to the international landscape, with a view of considering the South African context.

4. RESEARCH QUESTIONS

Given international trends and efforts to promote 21st century skills with STEM education and incorporating computational thinking (CT) in curricula, certain concerns have come to the fore regarding the South African secondary school system. To explore this, the following three questions have been formulated:

1. What were the changes in the content of the syllabi of Mathematics, Physics and Computer Science (Information Technology) over four decades at the FET level?

2. Is there alignment and/or integration between Mathematics, Physics and Computer Science content in the current FET curriculum?

3. Would the alignment or integration equip a learner at the Grade 12 exit level to utilise 21st century CT skills when navigating the complex world of work or future study?

5. METHOD

In this study an exploratory research design was adopted to examine whether there has been any meaningful changes in what has been taught in South African schools in the three disciplines, over the past four decades, using content analysis of representative current textbooks, and of the years around 1980, to detect changes over time. This would depict the implemented curriculum at the meso-micro levels (Van den Akker, 2004).

Alignment of the three disciplines was explored by comparing the sequencing of topics in the current syllabi of Mathematics, Information Technology and the Physics part of Physical Sciences. It was done to check for interdisciplinary horizontal linking and vertical structuring (Michelson, 2015) of the final three years of school, namely Grades 10, 11 and 12. In addition, the 2020 "Suggested Planning of Teaching and Assessment" documents of one of the provinces in South Africa (WCED, 2020) was consulted. It provided an additional window to the current interpretation of the intended curriculum as it plays out at the classroom level.

The syllabi cover large numbers of topics in all three subjects. For this paper it was not possible to investigate all topics in detail, something that could follow in future. A topic from Physics was selected as an example of alignment. Physics as application domain relies on Mathematics as a "language" and Computer Science or Information Technology as a "tool" (Figure 4). After 40 years "Motion" in Physics still is the first topic encountered by learners in Mechanics (Table 1). It is a topic that poses serious learning challenges (Hake, 1987; Halloun & Hestenes, 1985; McDermott *et al.*, 1987) and relies on crucial pre-knowledge in Physics and Mathematics (Basson, 2002) with Computer Science included here.

Curriculum and syllabi documents were scanned to reveal possible CT integration or a similar CT integrated taxonomy (Weintrop, 2016).

6. RESULTS AND DISCUSSION

6.1 Subject content spanning forty years

Prior to Y2K, learners in South Africa received focused tuition in two languages and a minimum of four subjects of choice in their final two school years (Grades 11 and 12). Since then, they have to study two languages, Life Orientation and Mathematics or Mathematical Literacy as compulsory subjects, in conjunction with a minimum of three subjects of choice over the final three years of school (Grades 10, 11 and 12) (DBE, 2021). This is a significant difference in approach and regarding what is expected of learners. The second major difference is that Physics and Chemistry used to be combined as Science in Grade 10, and separated for Grades 11 and 12, presenting Physics only in Grade 11 and Chemistry only in Grade 12. Currently, the Physics and Chemistry content is presented in all three grades as Physical Sciences (DBE, 2011). Table 1 shows the content of the Physical Sciences textbooks, representative of the early and latter parts of the forty-year period.

The basic Physics content stayed the same over this period. A couple of topics were removed – these relate to aspects of "Heat" (heat capacity, latent heat and thermionic emission), "two-dimensional projectile and circular motion" and "nuclear reactions". The "Doppler Effect" seems to be the topic expanded on in the current syllabus, including "frequency calculations", while having only descriptions about shock waves before.

Similar to Physics, the basic content of Mathematics remained the same (Table 2). The difference being that some content was added and seemingly nothing removed. The new content covers aspects of "Financial Mathematics", "Statistics" and "Probability" in all three grades, as well as "Linear programming" in Grade 11, and "Differential calculus" in Grade 12. Linear programming was introduced a couple of years ago and in the meantime removed, but it still appears in some textbooks as a topic.

During the same time, the implemented Computer Science curriculum changed substantially, with the introduction of Information Technology (IT) at the school level as a replacement for Computer Science. The topics changed from the "Classification of numbers", "Arithmetic operations", "Boole algebra", "Data handling" and "Fortran as programming language", to the inclusion of aspects related to the "Internet", "World Wide Web", "Algorithms" and "Data base design", among a spectrum of topics with a wide choice of tools to navigate the digital space (Table 3). Computing hardware advanced phenomenally and, with that, the development of applications and software. The introduction of "Coding", even at primary school level, also receives attention (Khoza, 2021). The value adding objective seems to be questioned and under consideration and discussion (Van der Velden, 2019).

6.2 Sequence of topics related to "motion"

To ascertain the level of alignment, requires that there be a closer look at the sequencing of topics, as prescribed or presented. Table 4 shows the details pertaining to "Motion", as the selected critical topic. It was taught previously as continuous arrangement of subtopics in Grade 11 only. Currently, the subtopics are intertwined with other Physics topics, as well as Chemistry topics, which are spread over Grades 10–12 (Table 1). Apart from the concepts related to "circular and parabolic motion", which have been removed (green in Table 4), all the subtopics seem to be presented in a similar sequence, although it spans over three years, compared to one year previously.

Tables 2 and 3 provide an overview of the content in Mathematics and Information Technology (marked with a hash) that supports the topic, "Motion". When compared with the results of a previous study (Basson, 2002), the Mathematics content is adequate and appropriate. The concern is the alignment of topics that span over the three years. An example is that aspects of "Functions", "Analytical geometry" and "Trigonometry", studied in Grade 11 Mathematics, would be required for Grade 10 Physics topics related to vectors, when studying "Motion". "Functions" in Grade 10 Mathematics provides an introduction to the linear function showing the effect of varying the gradient and y-intercept and to the quadratic function dealing with shape, vertical shift and the turning point. In Grade 11 the linear function is part of Analytical Geometry when the concepts of inclination and parallel and perpendicular lines are discussed. The quadratic function though remains a "Functions" topic and learners are introduced to a different form of this function as well as the average gradient concept. Learners studying Motion in Grade 10 could benefit from all of these Grade 11 Mathematics topics. In Trigonometry, trigonometric ratios, special angles and the Cartesian plane are introduced to assist with determining lengths in Grade 10. But Grade 11 trigonometric identities and some of the reduction formulae and the area rule would be useful tools when Motion is introduced.

Other examples are the introduction of “Calculus” and “Pythagoras’ theorem”, towards the end of Grade 12. These are indispensable for Physics, but at this point, it is too late to contribute towards the initial learning of complex concepts, for example, velocity, acceleration and projectile movement in a unit about “Motion”. It is more difficult to observe the relation with IT. The concepts that would be appropriate to encounter before or along with the teaching of motion deal with programming. These, together with the necessary skills, appear in the “practical” units of IT. The advantage would only be meaningful in Grade 12, after completion of all these units.

Table 1. Content of Physical Sciences textbooks, representative of the years, 1980 (Myburgh *et al*., 1978; Pienaar & Walters, 1975; Prinsloo, *et al*., 1976) and 2020 (Siyavula, 2020). The focus is on the Physics part, indicated by the colour, yellow. The red text shows the topics that have been removed.

1980 Physics and Chemistry Textbooks		**2020 Physical Sciences Textbooks**	
Grade 10 Science (Physics and Chemistry)		**Grade 10 Physical Sciences**	
1	Light (sources, energy, speed, reflection, refraction, colour)	1	Skills for science
2	Sound (sources, waves, speed, reflection, refraction, intensity, shock waves)	2	Classification of matter
3	Heat, work and energy (phases of matter, heat transfer, heat capacity, latent heat)	3	States of matter and kinetic molecular theory
4	Electricity (current, resistance, heat & magnetic effects of current, induction, transformer)	4	The atom
5	Structure of the atom	5	Periodic table
6	Atomic models	6	Chemical bonding
7	Model of electron arrangement	7	Transverse pulses and waves
8	Chemical bonding	8	Longitudinal waves and sound
9	Chemical reactions	9	Electromagnetic radiation
10	Acids, bases and salts	10	Particles that atoms are made of
11	Chemical reactions and electricity	11	Physical and chemical change
12	Ionic reactions	12	Representing chemical change
Grade 11 Physics		13	Magnetism
1	Mathematical relationships	14	Electrostatics
2	Motion and vectors	15	Electric circuits
3	Uniform and accelerated motion	16	Reactions in aqueous solution
4	Free fall and equations of motion (projectile motion)	17	Quantitative aspects of chemical change
5	Force and motion (Newton I, acceleration, momentum, weight)	18	Vectors and scalars (applications mainly forces)
6	Forces in equilibrium	19	Motion in one dimension (speed, velocity, acceleration, equations of motion)
7	Newton’s law of gravitation (gravitational force, circular motion, orbits)	20	Mechanical energy (potential and kinetic energy, conservation of mechanical energy)
8	Conservation of momentum (impulse, momentum, Newton III, action and reaction)	21	The hydrosphere

1980 Physics and Chemistry Textbooks		2020 Physical Sciences Textbooks	
9	Work, energy, power (potential, kinetic, energy conservation)	**Grade 11 Physical Sciences**	
10	Electrostatics	1	Vectors in two dimensions (context of forces)
11	Electric field and potential difference	2	Newton's laws (Newton I, II, III, gravitation, weight)
12	Electrical current and electromagnetism	3	Atomic combinations
13	Force between electrical currents, magnetic induction	4	Intermolecular forces
14	Resistance in electrical circuits	5	Geometrical optics
15	Electrical energy and power	6	2D and 3D wave fronts
16	Alternating current and the transformer	7	Ideal gases
17	Thermionic emission	8	Quantitative aspects of chemical change
18	Waves and their properties	9	Electrostatics
19	Wave nature of light	10	Electromagnetism (field, current, Faraday's law)
20	Electromagnetic waves	11	Electric circuits (Ohm's law, power, energy)
21	Electrons & positive current (deflection, photoelectric effect)	12	Energy and chemical change
22	Wave particle duality	13	Types of reaction
23	Atomic nucleus	14	The lithosphere
24	Nuclear reactions	**Grade 12 Physical Sciences**	
Grade 12 Chemistry		1	Momentum and impulse
1	Periodic table and electron configuration	2	Verticle projectile motion in one dimension
2	Chemical bonding	3	Organic molecules
3	Chemical calculations	4	Work, energy and power (conservation of energy)
4	Gases, liquids and solids	5	Doppler effect
5	Speed of chemical reactions	6	Rate and extent of reaction
6	Electrolytes	7	Chemical equilibrium
7	Redox reactions	8	Acids and bases
8	Hydrogen, oxygen and water	9	Electric circuits (series, parallel, internal resistance)
9	Alkali and earth metals	10	Electrodynamics (motors, generators, alternating current)
10	Halogens and transition elements	11	Optical phenomena and properties of matter (photoelectric effect, spectra)
11	Elements of groups 4-6	12	Electrochemical reactions
12	Organic chemistry	13	Chemical industry

Table 2. Content of Mathematics textbooks, representative of the years 1980 (Dekker *et al*., 1984; Kruger & Ahlers, 1975; Van der Schyf *et al*., 1975) and 2020 (Siyavula, 2020). The blue shows algebra and the green new content. Content supporting the topic, "Motion", in Physics is marked with a hash #.

1980 Mathematics Textbooks		**2020 Mathematics Textbooks**	
Grade 10 Algebra		**Grade 10 Mathematics**	
1	Products	1	Algebraic expressions: Real, rational and irrational numbers, rounding off, estimating surds, products, factorisation, simplification of fractions#
2	Decomposition in factors	2	Exponents: Revision of exponent laws, rational exponents, exponential equation#
3	Algebraic fractions	3	Number patterns: Describing sequences
4	Equations and inequalities: linear and quadratic	4	Equations and inequalities -Solving linear, quadratic equations & simultaneous equations, word problems, literal equations, solving linear inequalities#
5	Formulas: prisms, cylinders	5	Trigonometry: Similarity of triangles, trigonometric and reciprocal ratios, special angles, trigonometric equations, ratios in Cartesian plane#
6	Functions: linear, half circle, hyperbola, parabola with b=0	6	Functions: Linear, quadratic, hyperbolic, exponential and trigonometric functions, interpretation of graphs#
7	Systems of linear equations	7	Euclidean geometry: Triangles, quadrilaterals, mid-point theorem
8	Exponents	8	Analytical geometry: Cartesian plane, distance between two points, gradient & mid-point of a line#
Grade 10 Geometry		9	Finance and growth
9	Euclidian geometry: quadrilaterals, parallelograms, triangles	10	Statistics
10	Trigonometry: angles, Cartesian plane, six trig functions, right-angled triangle	11	Measurements: polygon, right prisms, cylinders, right pyramids, right cones & spheres
Grade 11 Algebra		12	Probability (union, intersection, Venn diagrams)
1	Factors, biggest common denominator, least common multiple and fractions		
2	Union and intersections	**Grade 11 Mathematics**	
3	Real number system	1	Exponents and surds: Rational exponents and surds, solving surd equations, applications of exponentials
4	Venn diagrams	2	Equations and inequalities: Completing the square, quadratic formula, substitution, finding the equation, nature of roots, quadratic inequalities, simultaneous equations#
5	Relations and functions	3	Number patterns: Quadratic sequences
6	The rest statement (cubic polynomials)	4	Analytical geometry: Equation and inclination of a line, parallel and perpendicular lines#

1980 Mathematics Textbooks		2020 Mathematics Textbooks	
7	Linear functions, equations and inequalities	5	Functions: Quadratic, hyperbolic & exponential functions, Sine, cosine & tangent
8	Hyperbola and circle	6	Trigonometry: Trigonometric identities, reduction formula, trigonometric equations, area, sine & cosine rules#
9	Exponents, powers and square roots	7	Measurement: Area of a polygon, right prisms, cylinders pyramids, and cones, spheres
8	Hyperbola and circle	8	Euclidean geometry: Circle geometry
9	Exponents, powers and square roots	9	Finance, growth and decay
Grade 11 Geometry		10	Probability
10	Locus	11	Statistics
11	Circle and cords of the circle	12	Linear programming - Introduction
12	Angles in a circle		
13	Tangent to a circle	**Grade 12 Mathematics**	
14	Intersection	1	Sequences and series
15	Relations and proportionality	2	Functions: Functions & relations, inverse, linear, quadratic & exponential functions#
16	Analytical geometry	3	Finance
Grade 12 Algebra		4	Trigonometry: Compound & double angle identities, solving equations, applications of trigonometric functions#
1	Exponential and logarithmic functions	5	Polynomials: Cubic polynomials, remainder theorem, factor theorem, solving cubic
2	Logarithms	6	Differential calculus: Limits, differentiation, differentiation rules, equation of tangent to curve, second derivative, sketching graphs, applications#
3	Quadratic equations with one unknown	7	Analytical geometry: Equation of a circle and of a tangent to a circle
4	Quadratic functions, quadratic inequalities and the nature of the roots	8	Euclidean geometry: Ratio and proportion, polygons, triangles, similarity, Pythagorean theorem#
5	Two equations with two unknowns, quadratic and linear	9	Statistics
6	Interpretation of graphs	10	Probability
7	Relations and proportionality		
8	Sequences and series		
9	Real number system II		
Grade 12 Geometry and Trigonometry			
10	Naming triangles, positive & negative angles		
11	Trigonometric functions		
12	Natural & logarithmic tables of trig relations		
13	Trigonometric relations of angles in any quadrant		
14	Relations of sides and angles of any triangle		

1980 Mathematics Textbooks		2020 Mathematics Textbooks	
15	Function values of specific angles		
16	Relations between trigonometric ratios		
17	Trigonometric formulas compound angles		
18	Graphs of trigonometric functions		
19	Identities and trigonometric equations		

Table 3. Content of Computer Science books, representative of the years 1980 (Computer Science Notes, no textbook prescribed at the time) and 2020 (DBE, 2020a). Content supporting the topic, "Motion", in Physics is marked with a hash #.

1980 Computer Science Notes		2020 Information Technology Textbooks	
Grade 11 and 12 Computer Science		**Grade 10 Information Technology**	
1	Computer science history and careers	1	Basic concepts of computing#
2	Classification of decimal numbers	2	Data representation storage and social implications
3	Conversion of number systems	3	Practical: Algorithms, Delphi, variables, components, solving basic mathematical problems using Delphi#
4	Arithmetic operations, binary system and alpha numeric characters	4	Basic concepts of hardware
5	Arithmetic calculations and the binary system	5	Basic concepts of system software
6	Data	6	Networks
7	Flow charts	7	Electronic communications
8	Flow charts and Fortran	8	Practical: Decision making, algorithms, Boolean expressions & operators, If-then & Nested if-then statements#
9	Boole algebra	9	Computer management
10	Input, output and storage media	10	The internet and World-Wide Web
11	Program storage computers	11	PracticalL Repetition, Do loop, string manipulation#
12	SAMOS machine	12	Internet services
13	Fortran programming language	13	Practical: practical assessment task
	– Assignment statement	**Grade 11 Information Technology**	
	– Input and output	1	Hardware - cache, memory
	– Program execution and development	2	Software - operating systems, compilers
	– Do statement	3	Networks and social implications
	– Subscripted variables	4	Practical: Functions and nested loops#
	– Functions and subroutines	5	Computer management
	– Case studies	6	Electronic communications
		7	Database management and design
		8	Practical: arrays, string and date manipulation#
		9	Database management and design
		10	Internet and www
		11	Internet services technologies
		12	Practical: text files, procedures, functions, user interfaces, databases#

1980 Computer Science Notes		2020 Information Technology Textbooks	
		Grade 12 Information Technology	
		1	Database Management - collection, warehousing, mining
		2	Database design concepts
		3	Practical: Programming fundamentals, procedures and function in Delphi libraries, user-interface, databases#
		4	Hardware - mobile technologies, performance of computers
		5	Software - cloud computing, viral and augmented reality
		6	Practical: OO-oriented programming, 2-dim arrays#
		7	Internet services, networks
		8	E-communication
		9	Social implications
		10	Practical - Databases and SQL

Table 4. Details and sequence of the topic, "Motion" (green shows subtopics removed).

1980 Physics topic MOTION		2020 Physics topic MOTION	
Grade 11		Grade 10	
1	Motion and vectors	1	Vectors and scalars (note: applications mainly forces)
	– Path length,distance and displacement, direction		– Introduction
	– Speed and velocity		– Properties of vectors
	– Scalars and vectors		– Techniques of vector addition
	– Adding of displacements and velocities	2	Motion in one dimension
	– Decomposition of vectors		– Reference frame
2	Uniform and accelerated motion		– Speed and velocity
	– Uniform motion in a straight line		– Acceleration
	– Uniform velocity & acceleration, displacement and velocity time graphs		– Instantaneous velocity and speed
			– Description of motion
3	Free fall and equations of motion		– Equations of motion
	– Free fall and air resistance		Mechanical energy
	– Gravitational acceleration	3	– Potential energy
	– Equations of motion and calculations		– Kinetic energy
	– Acceleration at an angle with the direction of motion		– Mechanical energy
	– Horizontal and upward projection (two dimensions)		– Conservation of mechanical energy
4	Force and motion		
	– Nature of force	Grade 11	
	– Uniform motion without force	4	Vectors in two dimensions (note: context of forces)
	– Newton's first law		– Resultant and perpendicular vectors
	– Inertia and mass		– Components of vectors
	– Force and acceleration	5	Newton's laws

	– Momentum		– Force
	– Weight and measurement of mass		– Newton's laws
5	Forces in equilibrium		– Forces between masses
	– Vector nature of force		(Newton's law of universal gravitation, weight and mass)
	– Equilibrant and resultant of forces		
	– Parallelogram, triangle, polygon of forces	**Grade 12**	
	– Decomposition of forces	6	Momentum and impulse
6	Newton's law of gravitation		– Momentum
	– The moon in free fall		– Newton's second law revisited
	– Gravitational force at a distance and on a mass		– Conservation of momentum
	– Law of gravitation and constant		– Impulse
	– Centripetal force and acceleration		– Physics in action: impulse
	– Circular motion	7	Vertical projectile motion in one dimension
	– Effects of centripetal force, mass, radius on speed of object		– Introduction
	– Orbit and period of a satellite		– Vertical projectile motion
7	Conservation of momentum	8	Work, energy and power
	– Impulse and momentum		– Work
	– Changes in and total momentum		– Work-energy theorem
	– Conservation of momentum during a collision		– Conservation of energy
	– Newton's third law, Action and reaction		– Power
8	Work, energy and power		
	– Work		
	– Potential, kinetic and forms of energy		
	– Power		
	– Conservation of mechanical energy		

6.3 Physics, Mathematics and Computer Science alignment

The "Suggested Planning of Teaching and Assessment" documents for Grades 10–12 (WCED, 2020), of the 2020 secondary school year (Tables 5 to 7, respectively), show that the planning calendar provided for 42 weeks of learning and assessment activities. In these tables, it is notable that the content is split into chunks of alternating subtopics, in relation to all three disciplines. In Mathematics, bits of "Algebra" alternate with bits of "Geometry" and "Trigonometry", with the new content, "Statistics" and "Finance", presented towards the end of the school year. In Physical Sciences, bits of "Physics" and "Chemistry" alternate, but even within "Physics", some "Mechanics", "Electricity", "Magnetism" and "Optics" alternate through the grades. Within the topic of "Motion", for example in Grade 10, "Energy" ideas go hand in hand with "Speed" and "Velocity". Coherence is lost when these subtopics are detached and presented with six weeks of "Chemistry" in between. Information Technology shows less fragmentation, but it appears that theoretical aspects are separated from practical programming tasks.

The National Curriculum Statement (NCS) emphasises progression of content and context as one of the guiding principles (DBE, 2021). It seems to be achieved in the lower to higher grades, but none of the curriculum documents referenced provided an explanation or justification for the chunking of the content and for the specific sequencing of the bits, as described above and shown in the tables. Further exploration of these aspects would be required to get a better understanding of how it could benefit or affect the learning of FET learners. It should also be explored in light of the reality that learners write separate Physics and Chemistry papers in Grade 12, and that “Algebra”, “Functions”, “Finance” and “Differential Calculus” form part of Mathematics Paper 1, which is separate from “Geometry”, “Trigonometry” and “Statistics”, assessed in Mathematics Paper 2.

The topic of “Motion” is revisited to ascertain alignment of the topic across the three disciplines. Tables 5 to 7 show the subtopics in green for Physics and the supporting Mathematics topics in blue and for Information Technology in orange. The Mathematics required comes in the first half of the year for Grade 10 and in this way supports the introduction of “Motion”, presented in the second half. Information Technology subtopics run parallel with Mathematics and could be useful by the time “Loops” are introduced later. Inspection of the details of the planning calendar for Grade 11 does not bode well for Grade 11 learners. “Analytical geometry”, “Trigonometry” and aspects of “Euclidian geometry” follow on “Vectors” in two dimensions, “Force and free body diagrams” and “Newton’s laws” in Physics. Ideally, these Mathematics subtopics should be pre-knowledge for the topics covered in Physics. Similarly for Grade 12, “Functions” and “Differential calculus” should come before “Momentum”, “Projectile motion”, “Work” and “Energy”, or these subtopics should even rather be taught in Grade 11.

The first reference to computational thinking was found in Grade 11 Information Technology within seven weeks of “Application development” and “Event driven programming”. It appears with specific reference to dataset handling and therefore no immediate link to physics. The same applies to Grade 12 Information Technology, where the focus and context is “SQL” and the “Internet”.

The NCS (DBE, 2021) aims to “produce learners that are able to demonstrate an understanding of the world as a set of related systems by recognising that problem solving contexts do not exist in isolation”. Neither the macro nor the meso/micro levels seem to support this aim of achieving alignment across the disciplines, or with aspects of interdisciplinarity as a possible framework or objective.

6.4 Assessment driven system

The intension of this study at the onset was not to consider assessment per se. While analysing the sequencing of the weekly learning activities (Tables 5 to 7), it became inevitable to observe and comment on the emphasis on formal assessment (tests and examinations as per the planning calendars) in Grades 10 to 12. The South African secondary school system at the FET level seems to be driven by a rigid, prescribed assessment scheme, as shown by an analysis (Table 8) of the activities indicated in Tables 5 to 7. In 2020, learners spent, on average, about 30% of the 42-week school year in Grades 10 and 11 on formal assessments. This number increases astoundingly to about 50% in Grade 12. To put it explicitly, learners devote only half of their time learning and developing new concepts and skills in their final year of school.

In spite of the focus on assessments, especially in Grade 12, the results are not in support of the tremendous effort spent to prepare for tests and examinations. Figure 5 shows the Grade 12 final examination results for Mathematics and Physical Sciences. Over the five-year period 2016–2020, on average, only 22% of candidates obtained 50% or more in Mathematics and 28% in Physical Sciences. It is alarming to note that about half of the learners do not even reach the 30% mark in Mathematics and only a fifth gets above 50%! There is unfortunately no data in the diagnostic reports of the DBE for Information Technology.

Table 5. Grade 10 planning calendar (grey shows assessment activities).

Week no.	Grade 10 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
1	Alg: rational/irrational numbers, surds, rounding, multiply bi- with trinomial	Revise matter and classification	Basic concepts of computing
2	Alg: factorisation (grouping, quadratic, sum & difference of cubes), simpl fract	States of matter and kinetic molecular theory Experiment 1	Basic concepts of computing: algorithms
3	Alg: exponents (laws, simplify, solve equations)	The atom basic building block	Data representation: bits, bytes, number systems, data types
4	Equations and inequalities: quadratic	Periodic table	Algorithms: flow charts, trace tables
5	Equations and ineq: quadratic, simultaneous linear equations	Chemical bonding	Data representation: file naming and types
6	Eq and ineq: word problems, literal eq's, linear inequalities	Transverse pulses on a string or spring	Variables: naming, assigning values, data types
7	Euclidean geometry: kite, parallelogram, rectangle, rhombus, square, trapesium	Longitudianal waves	Functions: random, round, sq root, calculations
8	Eucl geo: line segements joining midpoints of two sides of triangle	Sound	Social implications; licence, copyright, ethics, legal
9	Trigonometry: Trig ratios, reciprocals, special ratios	Electromagnetic radiation	Applying algorithms, swapping values, isolate digits
10	Trigonometry: solve simple eq's, use diagrams to determine ratios	Indiginous knowledge systems - folklore	Event handling
11	Analytical geom: Distance formula, gradient of line, coordinates midpoints	Magnetism	Extend use of variables, nested if's, relational operators
12	Applications of week 11	Electrostatics	Boolean logic, operators
13	Number patterns: linear	Electric circuits	Strings: methods and operations
14	Functions: concept of a func, basic graphs x^2, 1/x, b^x	Electric circuits	String operations, system software
15	Functions: sketching of x^2, 1/x, b^x	Particles substances are made of	Events and validation
16	Functions: finding eq of the form x^2, 1/x, b^x	Physical and chemical change	Debugging and networks
17	Functions: trigonometry graphs	Representing chemical change	e-Communication and implications
18	Examination	Revision	Problem solving
19	Examination	Examination	Examination
20	Examination	Examination	Examination
21	Examination	Examination	Examination
22	Trigonometry graphs problems in 2 dim	Vectors and scalars	Iteration constructs: loops

Week no.	Grade 10 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
23	Trigonometry graphs problems in 2 dim	Motion in one dimension	Loops and computer management
24	Statistics	Motion in one dimension	Computer management
25	Statistics	Instantaneous speed and velocity	String handling
26	Probability	Equations of motion Experiment 2	Internet and WWW, implement algorithms
27	Probability	Reaction in acqueous solution	Internet and WWW, application development
28	Finance growth	Reaction in acqueous solution	Application development
29	Finance growth	Reaction in acqueous solution	Application development
30	Measurement: Volume and surface areas	Quantitative aspects of chemical change	Solution development
31	Measurement: Volume and surface area spheres, pyramids, cones	Quantitative aspects of chemical change	Practical Assessment Task (PAT)
32	Measurement: Volume and surface area spheres, pyramids, cones	Quantitative aspects of chemical change	PAT
33	Eucl geo: appl quadrilateral theorems	Energy	Internet services technology
34	Eucl geo: appl quadrilateral theorems	Energy potential and kinetic	Solution development
35	Revision	Energy potential and kinetic	PAT
36	Revision	The hydrosphere	PAT
37	Revision	Revision	Revision
38	Examination	Examination	Revision
39	Examination	Examination	Examination
40	Examination	Examination	Examination
41	Examination	Examination	Examination
42	Examination	Examination	Examination

Table 6. Grade 11 planning calendar (grey shows assessment activities).

Week no.	Grade 11 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
1	Exponents and surds	Vectors in 2 dimensions	Hardware
2	Exponents and surds	Newtons laws, kinds of forces	Loops: nested
3	Equations and inequalities: quadratic, factors	Newtons laws, force diagrams and free body	Arrays as data structure 1D
4	Equations and inequalities: quadratic inequalities	Newtons laws, applications 1,2,3	Arrays basic operations
5	Equations and inequalities: simultaneous eq's, nature of roots	Newtons laws, applications 1,2,3	Arrays searching and sorting
6	Euclidian geometry: circle	Newtons laws, applications 1,2,3 Experiment 1	Arrays parallel and nested loops

Week no.	Grade 11 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
7	Eucl geom: apply theorems to geometry sketches with angles given as variables	Newtons laws, universal gravitation	String manipulation
8	Eucl geom: apply theorems to geometry sketches with angles numerical	Molecular structure	Computer management
9	Trig: tan, square identities, reduction formulae	Intermolecular forces	Methods string manipulation
10	Trig: neg angles, values for which identities hold	Control test	Problem solving: algorithms for string manipulation
11	Anal geometry: equation of line	Geometrical optics: refraction	Input and output text and file
12	Anal geometry: inclination of line	Geometrical optics: Snell's law	Electronic communication
13	Number patterns	Geometrical optics: Critical angle	Functions, arguments vs parameters
14	Number patterns	Wave fronts 2D and 3D: Diffraction	Social implications
15	Functions: parabola	Ideal gases, thermal properties	Software engineering principles
16	Functions: a/(x+p), ab^(x+p)	Ideal gas law	Practical Assessment Task (PAT)
17	Functions: exam questions integrating weeks 15 and 16	Quantitative aspects of chemical change	Practical Assessment Task (PAT)
18	Examination	Quantitative aspects of chemical change	Examination
19	Examination	Examination	Examination
20	Examination	Examination	Examination
21	Examination	Examination	Examination
22	Functions: effect of parameters in sin, cos, tan	Coulomb's law	PAT database management
23	Measurement: revise grade 10	Electric field, electromagnetism	PAT database design
24	Trigonometry: sin and cos rules	Magnetic field and Faraday's law	Database design
25	Trigonometry: area rules	Ohm's law Experiment 2	Database design, social implications
26	Trigonometry: problems in 2D applying weeks 24 and 25	Ohm's law power and energy	Application development
27	Statistics	Energy and chemical change	PAT application development
28	Statistics	Types of reaction: acid-base	Appl dev: computational thinking & software eng
29	Probability	Types of reaction: acid-base	Appl dev: computational thinking & software eng
30	Probability	Types of reaction: redox	Appl dev: computational thinking & software eng
31	Finance growth and decay	Control test	Appl dev: use of algorithms

Week no.	Grade 11 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
32	Finance growth and decay	Control test	Practical Assessment Task (PAT)
33	Finance growth and decay	Oxidation number	Database design
34	Finance growth and decay	Exploiting lithosphere or earth's crust	Database design and GUI
35	Revision	Exploiting lithosphere or earth's crust	Internet and WWW and GUI
36	Revision	Revision	Internet solutions and GUI
37	Revision	Examination	Social implications and PAT
38	Examination	Examination	Practical Assessment Task (PAT)
39	Examination	Examination	Examination
40	Examination	Examination	Examination
41	Examination	Examination	Examination
42	Examination	Examination	Examination

Table 7. Grade 12 planning calendar (grey shows assessment activities).

Week no.	Grade 12 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
1	Number patterns, sequences & series	Skills for practical investigations	Database design and concept
2	Number patterns, sequences & series	Newton law 2 and momentum	OOP and hardware
3	Number patterns, sequences & series	Impuls	OOP and software
4	Euclidian geometry: ratio, proportionality theorem & appl	Conservation of momentum	SQL
5	Euclidian geometry: similarity theorem & appl	Vertical projectile motion	Practical Assessment Task (PAT)
6	Trig: compound angle, double angle	Organic molecular structure	SQL and networks
7	Trig: identities involving week 6	IUPAC naming and formulae	SQL and e-Communication
8	Trig: eqs involving week 6	Applications of organic chemistry	SQL and social implications
9	Trig: graphs and solutions of triangles in 3D involving week 6	Plastics and polymers	Sotware engineering principles
10	Anal geom: circle with centre (a,b)	Control test	Sotware engineering principles
11	Anal geom: eq. of tangent to circle	Work def & work-energy theorem	Practical Assessment Task
12	Functions: definition and inverse of linear, x^2 and b^x	Conservation of energy non-conserv forces	Computer management and PAT
13	Func: def of log, inverse of exp and log	Doppler effect	Arrays 2D as datastructure
14	Func: polynomials 3rd degree	Rates of reaction	Arrays 2D as datastructure

Week no.	Grade 12 Planning Calender 2020		
	Mathematics	**Physical Sciences**	**Information Technology**
15	Differential calculus: limit, gradiet, find derivative	Chemical equilibrium	Softw eng: algorithmic thinking
16	Diff calc: stas points & concavity, sketch func's & its deriv, eq. of func	Equilibrium constant	Practical Assessment Task (PAT)
17	Differential calculus: applications	Acid-base reactions	Practical Assessment Task (PAT)
18	Examination	Acid-base reactions	Examination
19	Examination	Examination	Examination
20	Examination	Examination	Examination
21	Examination	Examination	Examination
22	Finance growth & decay	Gr 11 Elec and Magn revision	PAT and software engineering
23	Finance growth & decay	Electrical machines motors and generators	PAT and software engineering
24	Statistics	Electrical machines alternating current	PAT and Internet and WWW
25	Statistics	Electrolytic and galvanic cells	Internet services and social implications
26	Counting & Probability	Electrode potentials and oxidatiton numbers	Database design concepts
27	Counting & Probability	Fertiliser industry	PAT and appl development
28	Revision	Photoelectric effect	Application development
29	Internal examination	Internal examination	Application development
30	Internal examination	Internal examination	Internal examination
31	Internal examination	Internal examination	Internal examination
32	Internal examination	Internal examination	Internal examination
33	Revision	Revision	Assessment tasks
34	Revision	Revision	Assessment tasks
35	Revision	Revision	Examination
36	Examination	Revision	Examination
37	Examination	Examination	Examination
38	Examination	Examination	Examination
39	Examination	Examination	Examination
40	Examination	Examination	Examination
41	Examination	Examination	Examination
42	Examination	Examination	Examination

Table 8. Percentage of time spent on assessment activities for the 2020 school year.

Subject	Grade 10	Grade 11	Grade 12
Mathematics	29	29	45
Physical Sciences	24	31	43
Information Technology	31	29	55

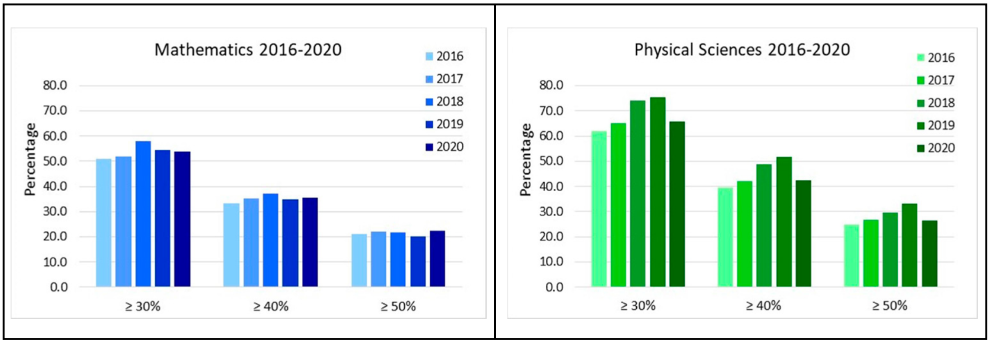

Figure 5. Grade 12 Mathematics and Physical Sciences examination results 2016–2020 (DBE, 2020b).

7. CONCLUSIONS

Twenty years into the millennium, the basic Physics and Mathematics content of the FET phase remained the same, while that of Information Technology has changed completely. When analysing syllabi, textbooks and planning schedules, there was no clear indication of whether there has been any consideration given to the alignment of the content of the three disciplines or how this will be realised. Without alignment and no integration of disciplines including aspects of computing, STEM could locally still be viewed as a collective term for the four subject areas represented by the acronym. It puts South Africa, to an extent, on the outside of the international frame regarding multi- or interdisciplinarity given STEM frameworks.

Chunking of content, as observed in this study, indicates neither alignment nor integration. At least two aspects should be clarified when further studies are pursued, preceding integration: (1) the impact and/or benefit of chunked content presented as alternating Physics and Chemistry topics in Physical Sciences, and alternating Algebra with Geometry-Trigonometry in Mathematics, given that no clear motive was found for it; (2) the need for spreading the content of critical topics over three years, compared to continuously per year, could shed light on the nature of vertical anchoring.

The South African basic education system appears to run an assessment-driven FET curriculum in Mathematics, Physics and Information Technology, with poor results as outcome. Such a system, seemingly, does not allow space for proper, integrated, interdisciplinary, 21st century skills development.

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