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Original Article

Assessing Cognitive Alignment in Pre-Tertiary TVET Core Mathematics: A Ghanaian Case Study of Curriculum and Exit Examination

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ABSTRACT

Mathematics plays a crucial role in pre-tertiary education, especially within STEM disciplines, where mastery of it enhances success in finance, engineering, and technology. Poor performance in the subject continues to delimit many pre-tertiary TVET learners. In our quest to find a lasting solution to this menace, many studies have been conducted to improve performance, but the problem persists in Ghana. What is yet to be done at the pre-tertiary TVET level is checking the alignment of the exit examinations with its curriculum. This study, therefore, investigates the cognitive alignment between Ghana's pre-tertiary TVET core mathematics curriculum and its exit examinations from 2011 to 2023. Using Webb's Depth of Knowledge (DOK) framework and Porter's Alignment Model, this study employs a pragmatic paradigm within a mixed-methods, and a convergent parallel design was used to gather both qualitative and quantitative. Eleven out of 13 exit examinations were randomly selected for content analysis. Data collection involved researcher-designed specification tables to categorize the cognitive demand levels of both the curriculum standards and examination questions. Content validity was established using the Item-Level Content Validity Index (I-CVI), yielding values of 0.89 and 0.91. Construct validity was confirmed with convergent validity ($r = 0.78$) and discriminant validity ($r = 0.24$), while inter-rater reliability, measured using Cohen's kappa ($\kappa = 0.83$, $p < 0.000$), indicated strong agreement in coding cognitive demand levels. The findings revealed that Paper 1 (multiple-choice) primarily assessed lower-order cognitive skills (DOK 1 and 2), whereas Paper 2 (constructed response) focused on higher-order thinking (DOK 2, 3, and occasionally 4). Cognitive alignment fluctuated across years, with the highest alignment index recorded in 2011 (0.819) and the lowest in 2019 (0.594). A weak positive correlation ($r = 0.241$, $p = 0.474$) between alignment and pass rate suggests that alignment alone does not strongly predict learner performance. The study recommends improving curriculum-examination alignment, ensuring a balanced representation of cognitive demand levels, and enhancing item development processes to better support learner achievement.

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INTRODUCTION

Mathematics is central to pre-tertiary education globally, particularly within the Science, Technology, Engineering, and Mathematics (STEM) fields. This is because they provide the foundation for disciplines such as finance, engineering, and data security (Maass *et al*., 2019). It is also a global phenomenon for pre-tertiary learners to pass the subject before being admitted to pursue higher education. It forms a chunk of most aptitude tests that people write to be recruited for jobs in many countries (Ahmed & Douglas, 2019). For this reason, many countries have stressed mastering the basics of the subject in their educational goals. In Ghana, there are two variations of mathematics studied at the secondary school level: Core Mathematics and Elective/Applied Mathematics. Whereas the latter is optional, the former is compulsory for all pre-tertiary learners, and progressing to the university to pursue further education requires a minimum grade of C6 (Credit) (Frempong & Asare-Bediako, 2016). The exit examination was written in May/June each year, with a residence scheduled for November/December for unsuccessful candidates. Core mathematics consists of two parts: Paper 1 and Paper 2. Paper 1 tested low-order cognitive skills using fifty (50) multiple-choice questions and lasted for 1 h and 15 minutes. Paper 2, which lasts for 2 hours and 30 minutes, tests high-order cognitive skills and consists of 13 questions, which are compartmentalized into four (4) sections. The first section has five (5) compulsory questions, the second has four (4) questions from which candidates are to choose two (2), and the third and fourth sections have two (2) questions each from which the candidate has to choose one (1) question each to make a total of nine (9). A total of 50 marks are allocated to Paper 1, while Paper 2 is allocated 100 marks in total. Core mathematics aims to equip learners with computational skills, problem-solving, abstract and precise thinking, and accuracy to a degree relevant to the problem at hand (COTVET handbook, 2020).

Despite the great importance of core mathematics in the academic and professional progression of pre-tertiary learners, they continue to perform abysmally in the subject (Ganyo *et al*., 2024). This stance was affirmed earlier by Boafo (2017), who argued that poor performance in mathematics significantly impacts the academic success of learners in Technical and Vocational Education and Training (TVET) institutions in Ghana, concluding that mathematics is crucial for the overall academic achievement of learners.

A large and growing body of literature has investigated the challenge of poor performance in mathematics at various levels of the academic ladder, using diverse methodologies. Mensah *et al.* (2023) used document and content analysis methods to address the issue of poor performance in mathematics for grades 4 to 6 learners. Their findings suggest that incorporating cultural games improves learners' proficiency, performance, and the perceived relevance of mathematical concepts. However, as this study was limited to learners in grades 4 to 6, its findings cannot be directly extrapolated to higher grade levels, such as grade 12. By contrast, Davis *et al.* (2021), Arthur *et al.* (2022), and Fokuo *et al.* (2022) tackled the problem in grades 10–12 using a survey method. Key findings from these studies included identified factors such as instructional materials, open-ended tasks, feedback, motivation, instructional quality, inadequate curriculum coverage, lack of learner interest, and negative perceptions as key barriers to performance.

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Despite these extensive attempts to address the issue of poor performance in mathematics in Ghanaian literature, grammar schools have dominated the landscape, with little to no attention given to pre-tertiary TVET learners. No previous study has investigated the cognitive alignment of curricula with exit examinations at the Ghanaian pre-tertiary TVET level. Furthermore, far too little attention has been paid to the use of Porter's alignment index to check the degree of alignment of curriculum standards with exit examinations at the pre-tertiary TVET level in Ghana.

Alignment studies have been widely used to assess whether curricula correspond to instructional materials, textbooks, and assessments. Qhibi *et al.* (2020) employed Webb's Depth of Knowledge (DOK) framework and Porter's Alignment Index to analyse the alignment between South African mathematics content standards and workbook activities, identifying both congruencies and gaps that inform curriculum development. Similarly, Kober (2018) used a mixed-methods approach to examine the impact of policy changes on curriculum alignment and demonstrated that shifts in educational policies can enhance instructional practices and learner performance. Bhatti *et al.* (2022) refined the SEC model to quantitatively measure alignment among curriculum, instruction, and assessment, focusing on cognitive demand and the number of learning objectives. While alignment correlates positively with academic achievement, ensuring consistent cognitive demands across all instructional contexts remains a challenge.

Li *et al.* (2020) further highlighted discrepancies in curriculum alignment, emphasizing that variations in implementation and teachers' interpretations of curriculum standards contribute to achievement gaps, particularly in under-resourced schools. Elsherbiny (2019) argued that alignment studies become particularly relevant when other interventions fail to yield meaningful improvements in learner performance. In the context of pre-tertiary TVET mathematics education in Ghana, a misalignment between what is taught and what is assessed may contribute to suboptimal learner outcomes. Forte (2017) underscored the importance of understanding curriculum alignment to ensure coherence between instructional delivery and assessment expectations. Additionally, Martone & Sireci (2009) suggested that alignment indices can serve as predictors of learner performance on exit examinations. Understanding this predictive relationship is critical for educational stakeholders, including curriculum designers and examination boards, because it informs the appropriate emphasis and resource allocation for aligning exit examinations with curriculum standards.

Addressing the cognitive alignment of exit examinations with curriculum standards may be a pivotal step toward improving mathematics performance at the pre-tertiary TVET level. By bridging this research gap, policymakers and educators can develop targeted interventions to enhance learners' outcomes in mathematics.

If the problem of poor performance in core mathematics is not tackled immediately, Ghana's dream of ensuring that learners develop the skills and knowledge required for success in a rapidly changing world will become a mirage. The nation will thus continue to produce a workforce that is not competitive and eventually becomes detrimental to the developmental agenda of developing through TVET. Learners performing abysmally in core mathematics are of grave concern to stakeholders in education because the subject plays a major role in shaping learners' cognitive and analytical abilities, which are crucial for their success in TVET disciplines. (Vasilev, 2024) Understanding the relationship between cognitive alignment and exit examinations, as well as learner outcomes can inform policy decisions and drive improvements in curriculum and assessment practices.

This study focuses on investigating the cognitive alignment between the pre-tertiary TVET Core Mathematics curriculum and exit-examination questions over a decade. Specifically, it seeks to address four key research questions: (1) What is the measure of the relative emphasis on cognitive demand levels in Paper 1 of the Core Mathematics exit examination? (2) What is the measure of relative emphasis on cognitive demand levels in Paper 2 of the Core Mathematics Exit Examination? (3) What is the overall cognitive alignment between the Core Mathematics exit examinations and curriculum

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standards? (4) How does the cognitive alignment of the curriculum and exit examinations affect learner pass rates in pre-tertiary TVET Core Mathematics?

MATERIALS AND METHODS

The pragmatism paradigm was adopted for this study to allow researchers to mix methods based on what best addresses the research problem at hand, thereby rejecting the notion of a single "best" scientific method (Kuranchie, 2021). The convergent parallel design was chosen for this study because the researchers gathered both qualitative and quantitative data in parallel rather than sequentially so that each dataset could be analysed independently (Creswell & Creswell, 2018). This study focused on 13 pre-tertiary TVET core mathematics examination papers from May to June 2011 to 2023, excluding November/December papers. This exclusion was based on the belief that resistant candidates perform better due to their familiarity with the examination conditions, allowing the research to concentrate on first-time test-takers.

The Cochran formula was used to determine the study's sample size of eleven (11) documents for content analysis, suitable for a small target population of 13 (13), accepting a 10% margin of error (Cochran, 1997). Analysing 11 out of the 13 exit-examination papers minimizes potential sampling error and ensures high representativeness due to the large proportion of the population analysed. The lottery method was used to randomly select documents for the study, ensuring each member had an equal chance of being chosen, thereby minimizing bias in a small population (Negida *et al*., 2017)

Data Collection Instruments

The study utilized two researcher-made instruments for data collection: specification tables for the pre-tertiary TVET mathematics curriculum and exit examination documents. The first specification table was used to extract the cognitive demand levels of the learning outcomes in the curriculum and had two columns: Learning Outcomes, and Depth of Knowledge Level. The second table unpacked the examination question content for the 11 papers among the four DOK levels. This structured approach facilitated comprehensive data extraction and analysis.

Validity and Reliability of Instruments

Content validity was established by categorizing cognitive demand levels representative of the curriculum and exit examinations. The Item-Level Content Validity Index (ICVI) value for both instruments was 0.89 and 091 which was greater than the threshold value of 0.78 (Ghahramanian *et al*., 2015). With a convergent validity of r=0.78 and discriminant validity of r=0.24, the construct validity of the research instruments was high, while face validity was reviewed by experts to confirm the relevance and accuracy of the measures (Fang et al., 2022). The inter-rater reliability, calculated using Cohen's Kappa, was 0.83 (n=100, $p<0.000$), confirming strong agreement between coding groups on cognitive demand classifications and quantification.

Data Collection Procedure

After obtaining ethical clearance, researchers collected and cleaned the data from official mathematics exit examination papers and curriculum documents in Ghana's pre-tertiary TVET ecosystem for analysis. Raw data were statistically processed and analysed to examine trends in cognitive demand levels. Paper 1 questions were assigned a value of 1, while Paper 2 open-ended questions were assigned values based on the official marks attached to each question. Secondary data from Paper 1 and curriculum objectives were the primary data sources for Research Question 1. Research Question 2 used data from Paper 2 and the curriculum. For research question 3, Porter's alignment model was used to assess how well the intended outcomes were reflected in the assessments. The computed alignment indexes and results from a Technical Institute addressed research question 4 using correlation and Granger causality tests to explore relationships between topic alignment and academic achievement.

Alignment Index Computation

To assess the alignment between Ghana's pre-tertiary TVET Core Mathematics Curriculum standards and Mathematics Exit Examinations, the

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data were organized into two specification tables. The first table represents the curriculum, with rows for depth of knowledge and columns for learning objectives, whereas the second table represents the unpacking of the Core Mathematics Exit Examination questions among the four depth of knowledge levels for each examination year. Based on this data, Porter's alignment index was computed.

$$P.I. = 1 - \frac{\sum_{i=1}^{n} |x_i y_i|}{2}$$

Porter's alignment index, computed using ratios, ranges from 0 to 1, where 0 indicates no alignment and 1 indicates perfect alignment (Matthews & Kyi, 2019). However, Bhaw & Kriek (2020) noted that Porter did not clearly define an index for assessing good alignment. This study utilized Webb's proposed value ranges to assess the degree of alignment: less than 0.6 signifies poor alignment, 0.6 to 0.7, weak alignment, and above 0.7 represents acceptable alignment; and 1, is an ideal scenario (Webb, 2007).

This study focused on the alignment between pre-tertiary TVET Mathematics Curriculum standards and the mathematics exit examination with respect to cognitive demand levels. Alignment indices for the examination period were calculated using Porter's alignment method. The curriculum encompasses four cognitive demand levels: Depth of Knowledge levels 1–4 (DOK 1, DOK 2, DOK 3, and DOK 4).

Content Areas and Learning Outcomes of Mathematics Curriculum and Core Mathematics Exit Examinations

Table 1: Depth of Knowledge and Number of Learning Outcomes in the Curriculum

Depth of Knowledge Levels	Levels in The Curriculum Standards	Percentages
DOK 1	31	31.31%
DOK 2	22	22.22%
DOK 3	33	33.33%
DOK 4	13	13.13%
TOTAL	99	100%

Table 1 presents the cognitive demand levels (depth of knowledge) with their corresponding percentage proportions.

RESULTS

Relative Emphasis of Cognitive Demand Levels in Paper 1 of the Core Mathematics Exit Examination Questions

Table 2: Core Mathematics Paper 1 Questions Classification Based on Official Mark Allocation

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	20	18	8	9	12	4	9	11	8	15	9
DOK 2	30	32	42	41	38	46	41	39	42	35	41
DOK 3	0	0	0	0	0	0	0	0	0	0	0
DOK 4	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**

Table 2 shows that the Paper 1 questions fall under DOK 1 and DOK 2 only. 2016 was the most difficult (4 DOK 1, 46 DOK 2), followed by 2013 and 2019 (8 DOK 1, 42 DOK 2, each). 2011 was the easiest (20 DOK 1 and 30 DOK 2).

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Table 3: Percentage Cognitive Spread of Curriculum and Exit Examination for Paper 1.

DOK	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	8.69	4.69	15.31	13.31	7.31	23.31	13.31	9.31	15.31	1.31	13.31
DOK 2	37.78	41.78	61.78	61.78	53.78	69.78	59.78	55.78	61.78	47.78	59.78
TOTAL	**46.46**	**46.46**	**77.09**	**75.09**	**61.09**	**93.09**	**73.09**	**65.09**	**77.09**	**49.09**	**73.09**

Table 3 shows the cognitive spread of Paper 1 for the various years. It shows that 2016 had the highest percentage (23.31%) for DOK 1, and 69.78% for DOK 2. On average, DOK 1 accounts for 11.58% of Paper 1 (multiple choice questions) and 55.60% for DOK 2. The entry values of this table came from taking the absolute difference between curriculum objectives (table 1) and the examination questions (table 2) put in percentage terms. The total row of the table shows the overall spread for each year. 2013 and 2019 exhibited a cognitive spread of 77.09% each with 2011 and 2012 recording the least cognitive spread of 46.46%.

Relative Emphasis of Cognitive Demand Levels in Paper 2 of the Core Mathematics Exit Examination Questions

Table 4: Core Mathematics Paper 2 Questions Classification Based on Official Mark Allocation

DOK	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	0	0	0	0	0	0	0	0	0	0	0
DOK 2	47	52	32	84	52	45	35	44	67	51	13
DOK 3	68	48	68	46	48	55	71	91	93	94	72
DOK 4	45	60	60	30	60	60	54	40	0	15	75
TOTAL	160	160	160	160	160	160	160	175	160	160	160

Table 4 shows that Paper 2 did not have DOK 1 questions. DOK 2 peaked in 2014 (84 points) and was lowest in 2023 (13 points). DOK 3 was the highest in 2020 (94 points) and lowest in 2014 (46 points). DOK 4 peaked in 2023 (75 points) and was absent in 2019.

Table 5: Percentage Cognitive Spread of Curriculum and Exit Examination for Paper 2.

DOK	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	0	0	0	0	0	0	0	0	0	0	0
DOK 2	7.15	10.23	2.22	30.23	10.28	5.90	0.35	2.92	19.65	9.65	14.10
DOK 3	9.17	3.33	9.17	4.58	3.33	1.04	11.04	18.67	24.79	25.42	11.67
DOK 4	14.50	24.34	24.37	5.62	24.37	24.39	20.62	9.73	13.13	3.76	33.74
TOTAL	**31.31**	**37.98**	**35.76**	**40.48**	**37.98**	**31.31**	**32.01**	**31.31**	**57.58**	**38.83**	**59.51**

The percentage cognitive spread of curriculum and exit examination for Paper 2 exhibited in Table 5 shows that 2023 had the highest cognitive spread of 59.51% while 31.31% is the least recording for the years 2011, 2016, and 2018.

Overall Cognitive Alignment Between the Core Mathematics Exit Examination and the Curriculum Standards

Table 6: Overall Classification of Core Mathematics Exit Examination Questions Based on Official Mark Allocation

DOK	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	20	18	8	9	12	4	9	11	8	15	9
DOK 2	77	84	74	125	90	91	76	83	109	86	54
DOK 3	68	48	68	46	48	55	71	91	93	94	72
DOK 4	45	60	60	30	60	60	54	40	0	15	75
TOTAL	210	210	210	210	210	210	210	225	210	210	210

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Table 6 confirms that each exam had 210 marker points, except for 2018 (225). DOK 2 peaked in 2014 (125 points), followed by 2019 (109 points), whereas 2023 had the lowest (54 points). Details of DOK 3 and 4 are listed in Table 3.

Table 7: Overall Classification of Core Mathematics Exit Examination Questions Based on Ratios

DOK	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	0.095	0.086	0.057	0.043	0.057	0.019	0.043	0.049	0.038	0.071	0.043
DOK 2	0.367	0.400	0.352	0.595	0.429	0.433	0.362	0.369	0.519	0.410	0.257
DOK 3	0.333	0.229	0.324	0.219	0.229	0.262	0.338	0.404	0.443	0.448	0.343
DOK 4	0.131	0.286	0.286	0.143	0.286	0.286	0.257	0.178	0	0.071	0.357
TOTAL	1	1	1	1	1	1	1	1	1	1	1

The ratios for each entry in Table 6 were divided by each year's total point marker. The results are presented in Table 7. This table levels entry with the curriculum objectives for easier comparison.

Table 8: Overall Cognitive Spread of Exit Examinations for the Entire Core Mathematics Paper

DOK	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DOK 1	0.218	0.227	0.256	0.270	0.256	0.294	0.270	0.264	0.275	0.242	0.270
DOK 2	0.144	0.178	0.130	0.373	0.206	0.211	0.140	0.147	0.297	0.187	0.035
DOK 3	0.000	0.105	0.010	0.114	0.105	0.071	0.005	0.071	0.110	0.114	0.010
DOK 4	0.000	0.154	0.154	0.012	0.154	0.154	0.126	0.046	0.131	0.060	0.226
TOTAL	**0.362**	**0.664**	**0.550**	**0.769**	**0.722**	**0.731**	**0.541**	**0.528**	**0.813**	**0.603**	**0.541**

The overall cognitive spread was computed by taking the absolute difference between the curriculum objectives ratios in Table 1 and examination questions ratios in Table 7. Table 8 shows the outcomes of these differences. The total value for each year provides the overall cognitive spread for each year.

Table 9: Alignment Index for Each Year Between Curriculum and Examination Questions

YEAR	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2023
DIFF.	0.362	0.664	0.550	0.769	0.722	0.731	0.541	0.528	0.813	0.603	0.541
A.I.	0.819	0.668	0.725	0.615	0.639	0.634	0.730	0.736	0.594	0.698	0.730

Table 9 shows the results of computing the alignment index for each year of the examination under review. The highest alignment index recorded was 0.819 in 2011, followed by 2018, 2017, 2023, and 2013 with indices of 0.736, 0.730, 0.730, and 0.725, respectively. 2019 had the lowest alignment index value at 0.594.

How Cognitive Alignment of Curriculum and Exit Examinations Affect Learner Pass Rates in TVET Core Mathematics

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Table 10: Difference Between Curriculum Outcomes and Exit Examinations

Year	Alignment Index	Pass Rate
2011	0.819	100.00
2012	0.668	84.75
2013	0.725	98.21
2014	0.615	69.19
2015	0.639	46.21
2016	0.634	33.28
2017	0.730	42.71
2018	0.736	65.24
2019	0.594	54.86
2020	0.698	42.33
2023	0.730	45.73

In Table 10, the alignment index for each year is presented along with the pass rate of learners in the participating TVET institution. This data formed the basis of the correlation conducted to determine the predictive power of cognitive alignment index in predicting learner outcomes. Spearman's rho was used to compute the correlation coefficients for the data for the simple reason that normality assumptions failed for the data.

Table 11: Correlations

			Year of Examination	Alignment Index of Entire Paper	Pass Rate for the year
Spearman's rho	Year of Examination	Correlation Coefficient	1.000	-.055	-.718*
		Sig. (2-tailed)	.	.873	.013
		N	11	11	11
	Alignment Index of Entire Paper	Correlation Coefficient	-.055	1.000	.241
		Sig. (2-tailed)	.873	.	.474
		N	11	11	11
	Pass Rate for the year	Correlation Coefficient	-.718*	.241	1.000
		Sig. (2-tailed)	.013	.474	.
		N	11	11	11

*. Correlation is significant at the 0.05 level (2-tailed).

Table 11 shows a weak positive correlation (0.241) between the Alignment Index and Pass rate over 11 years. The Alignment Index accounts for only 5.81% of the variance in the pass rates.

DISCUSSION

The Relative Emphasis of Cognitive Demand Levels in Paper 1

The findings indicate that Paper 1 of the Core Mathematics exit examination predominantly focuses on Depth of Knowledge (DOK) Levels 1 and 2, with no representation of DOK Levels 3 and 4. This pattern aligns with curriculum expectations that emphasize lower-order cognitive skills in multiple-choice assessments. However, the balance between DOK 1 and DOK 2 varies across the years. Table 2 shows that the number of DOK 1 questions fluctuated, with the highest in 2011 (20 questions) and the lowest in 2016 (4 questions). Meanwhile, DOK 2 consistently formed the majority of Paper 1 questions, peaking in 2016 (46 questions) and 2013/2019 (42 questions each). This confirms that Paper 1 primarily assesses basic recall and procedural understanding rather than higher-order cognitive skills. The percentage cognitive spread analysis in Table 3 further supports this observation. The cognitive spread of Paper 1 ranged from 46.46% (2011 and 2012) to a peak of 93.09% (2016), highlighting significant variations in the extent to which the examination aligns with curriculum cognitive demand expectations. The years 2013 and 2019 exhibited a cognitive spread of 77.09%,

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indicating a stronger emphasis on procedural rather than conceptual understanding.

These results align with findings by Liu *et al.* (2019) and Brookhart (2010), who argue that high-stakes mathematics examinations tend to prioritize lower-order thinking, potentially limiting students' ability to develop critical thinking and problem-solving skills. Polikoff (2012b) also suggests that misalignment in assessments can create opportunity gaps, preventing students from engaging with higher cognitive levels required for real-world problem-solving. To address this issue, examination bodies should consider integrating a balanced representation of cognitive demand levels by incorporating more DOK 3 and DOK 4 tasks into Paper 1. This approach would better reflect curriculum expectations and enhance students' readiness for higher-order mathematical reasoning.

The Relative Emphasis of Cognitive Demand Levels in Paper 2

Paper 2 of the Core Mathematics exit examination assesses higher cognitive demand levels, predominantly covering DOK Levels 2, 3, and 4, with no representation of DOK 1. This design is intentional, as Paper 2 primarily evaluates problem-solving, reasoning, and extended analytical thinking. Table 4 indicates that DOK 2 questions were present every year but varied significantly in weight. The highest allocation occurred in 2014 (84 points), while 2023 saw the lowest representation (13 points). DOK 3 questions were consistently included, peaking in 2020 (94 points) and reaching the lowest in 2014 (46 points). DOK 4, which involves complex problem-solving and synthesis, peaked in 2023 (75 points) but was absent in 2019. This inconsistency raises concerns about whether students are consistently exposed to the highest cognitive demand tasks. Table 5, which presents the percentage cognitive spread for Paper 2, shows significant variability. The highest spread was observed in 2023 (59.51%), whereas the lowest occurred in 2011, 2016, and 2018 (31.31%). Such fluctuations suggest that while Paper 2 aims to challenge students with higher cognitive demands, its implementation across different years has not been uniform.

These inconsistencies align with research by Polikoff (2012b) and Webb (2007), who emphasize that strong curriculum-examination alignment requires consistent representation of cognitive levels. The absence of DOK 4 in 2019 and its surge in 2023 suggests misalignment, potentially impacting students' preparedness for complex problem-solving tasks in TVET disciplines. To enhance alignment and assessment validity, examination bodies should standardize the distribution of DOK 2, 3, and 4 levels in Paper 2. Additionally, greater emphasis should be placed on maintaining a steady proportion of DOK 4 tasks across years to ensure students develop the necessary analytical and reasoning skills essential for success in TVET mathematics and beyond.

Overall Cognitive Alignment Between the Core Mathematics Exit Examination and the Curriculum Standards

Table 9 presents the computed alignment index (A.I.) between the curriculum and examination questions using Porter's model, where values closer to 1 indicate stronger alignment. The highest alignment was recorded in 2011 (0.819), reflecting strong adherence to curriculum standards. Most other years showed moderate alignment, with indices between 0.639 and 0.736 (e.g., 2017, 2018, and 2023). The lowest index was in 2019 (0.594), indicating significant misalignment. Higher alignment in years like 2011 suggests deliberate efforts to match examinations with curriculum standards, while the low index in 2019 points to potential gaps in translating the intended curriculum into assessment. Misalignment can lead to over- or under-representation of key topics, disadvantaging learners (Webb, 1997; Polikoff, 2012a). Studies emphasize that strong curriculum-examination alignment enhances assessment validity and instructional coherence, reinforcing targeted instruction and improving learner performance (Gamoran *et al*., 1997). The misalignment in 2019 aligns with Porter's (2002) findings that unclear curriculum standards or inconsistent item development processes contribute to discrepancies. Porter's model stresses balancing cognitive demand levels in assessments to ensure fairness. Lower alignment indices suggest an imbalance in this

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regard, potentially leading to biases in testing outcomes.

How Cognitive Alignment of Curriculum and Exit Examinations Affect Learner Pass Rates in TVET Core Mathematics

The analysis reveals a statistically significant negative correlation ($r = -0.718$, $p = 0.013$) between the year of examination and pass rates, indicating a decline in pass rates over time. This trend may suggest increasing exam difficulty, curriculum changes, or external factors affecting learner performance. A negligible negative correlation ($r = -0.055$, $p = 0.873$) between the year of examination and the alignment index suggests that alignment has remained relatively stable over the years. Additionally, a weak positive correlation ($r = 0.241$, $p = 0.474$) between the alignment index and pass rate, with a coefficient of determination ($r^2 = 0.0581$), indicates that alignment explains only 5.81% of the variation in pass rates. This suggests that while alignment is important, other factors such as teaching quality, learner preparedness, and socioeconomic conditions play a more critical role in learner success. Research by Polikoff (2012b) and Porter (2002) emphasizes the importance of curriculum-examination alignment in improving achievement, but this study's weak correlation supports findings that alignment alone is insufficient without addressing broader instructional and contextual challenges. Declining pass rates may stem from curriculum reforms, increased cognitive demand, or resource disparities (Gamoran et al., 1997; Oates, 2011). Polikoff et al. (2011) further highlight that, socioeconomic factors, teacher effectiveness, and assessment quality significantly impact learner outcomes, which may explain the weak alignment-pass rate relationship observed in this study.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study investigated the cognitive alignment between the Core Mathematics curriculum and exit examinations in Ghana's pre-tertiary TVET education system from 2011 to 2023. The findings reveal significant patterns in the cognitive demand levels assessed in the examination papers. Paper 1 predominantly assessed lower-order cognitive skills (DOK 1 and DOK 2), with no representation of higher-order thinking skills (DOK 3 and DOK 4). This suggests that while Paper 1 aligns with curriculum expectations for procedural knowledge, it does not adequately challenge students to develop problem-solving and analytical reasoning abilities. The variability in the percentage of cognitive spread over the years further indicates inconsistencies in the emphasis on different cognitive levels. Paper 2, designed to evaluate higher cognitive demand levels, primarily focused on DOK 2, DOK 3, and occasionally DOK 4, with DOK 1 entirely absent. While this paper aims to assess problem-solving and reasoning skills, inconsistencies in the distribution of DOK 4 questions suggest fluctuations in the alignment with curriculum expectations. The absence of DOK 4 in some years may disadvantage students who require consistent exposure to advanced problem-solving tasks. The overall alignment index between the curriculum and the exit examination fluctuated across the years. The highest alignment was observed in 2011 (0.819), whereas 2019 exhibited the lowest alignment (0.594). These variations indicate that while moderate alignment was generally maintained, certain years experienced significant deviations, potentially affecting instructional coherence and learner preparedness. The correlation analysis between cognitive alignment and learner performance demonstrated a weak positive relationship ($r = 0.241$, $p = 0.474$), with alignment explaining only 5.81% of the variance in pass rates. This suggests that while alignment plays a role in learner outcomes, other factors such as teaching quality, student preparedness, and instructional resources, have a more substantial impact on performance.

Recommendations

- Examination bodies should ensure consistent representation of all cognitive demand levels, particularly higher-order thinking tasks (DOK 3 and 4), to better reflect curriculum standards and promote critical thinking skills.
- Ongoing evaluation of curriculum-examination alignment should be institutionalized to ensure

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that assessments remain relevant, and reflective of curricular intentions.

- Examination bodies should regularly train item writers on curriculum standards and alignment frameworks.

Educational Implications

The overemphasis on lower cognitive demand levels (DOK 1 and DOK 2) in Paper 1 suggests a need for assessment reforms to encourage higher-order thinking skills. By incorporating more complex problem-solving tasks, examination bodies can better prepare learners for technical and vocational applications of mathematics. Similarly, ensuring the consistent representation of DOK 4 questions in Paper 2 will enhance the validity and fairness of assessments.

Additionally, the weak relationship between alignment and pass rates suggests that broader educational challenges must be addressed. While improving alignment is essential, it should be accompanied by initiatives such as enhanced teacher training, curriculum development, and student support programs. A comprehensive approach that integrates assessment reforms with instructional improvements will contribute to better mathematics achievement in Ghana's pre-tertiary TVET sector.

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