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Item Response Theory Detection of Items That Functioned Differentially in Philip Carter's Cognitive Ability Test Among Junior Secondary School Students in Ondo State, Nigeria

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Abstract

The study determined the test item that function differentially based on sex and school ownership and location among junior secondary students Ondo State These were with the view of ensuring the suitability of the use of Philip Carter's Cognitive Abilities Test among secondary junior students in Ondo State. The study adopted survey design. The population for the study comprised all junior secondary school students in Ondo State and the study sample consisted of 1080 students. Philip Carter's Cognitive Abilities Test was adopted for data collection. Data collected were subjected to Mantel-Haenszel DIF method of DIF assessment. The results showed that 14, 16 and 22 of the 30 items of the cognitive abilities test functioned differentially with respect to gender, school location and school type respectively. The study therefore concluded that some of the Philip Carter's Cognitive Abilities Test items in its original format are not suitable for measuring Ondo State Junior Secondary school students' cognitive ability.

Keywords: Item Response Theory (IRT), Items that Functioned Differentially, Cognitive Ability Test,

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Introduction

Recent observation in Nigeria had shown that the secondary school students' performance in both internal and external examinations has not been encouraging especially in mathematics and sciences subjects. This observation may due to not paying adequate attention to cognitive level of individual students at the point of entering secondary school as well as at the point of moving from one class level to the other. The experience and observation of some teachers and school administrators showed that secondary school students up to SS III cannot handle simple mathematical tables appreciably without using calculator. Scientific laws and theories can no longer be memorized or mastered with understanding, summarizing passages and constructively writing a story or an essay in English Language involving critical thinking is almost impossible.

This deplorable condition needs immediate attention. Although the cognitive ability is been worked upon at the primary school level, through the curriculum that includes both quantitative and verbal reasoning and they make use of relevant books and aptitude tests which improve the development of the cognitive ability of the pupils. The books span through all the classes (Pre-primary and primary classes). Unfortunately, it terminates at primary six, which should not be so. Hence this work is aimed at analysing items of a cognitive abilities scale with which cognitive abilities of secondary school students can be measured and thus give information on solving the deplorable condition.

Modern psychological theory views cognitive ability as multidimensional while acknowledging that the many different abilities are themselves positively correlated. This positive correlation across abilities has led most psychometricians to accept the reality of a general cognitive ability that is reflected in the full scale score on major tests of cognitive ability or Intelligent Quotient (IQ) (Asbury, et al., 2005).

Cognition, or cognitive processes, can be natural or artificial, conscious or unconscious. It can also be developed at any level, either as a child, adolescent or adult. Cognitive development is the construction of thought processes, including remembering, problem solving, and decision-making, from childhood through adolescence to adulthood. Useful enough, the cognitive abilities of a child can be measured through standardized tests such as the Aptitude tests, IQ tests, and the Cognitive Abilities tests (CAT, COGAT, DCAT). The cognitive ability test is another name for aptitude tests or intelligence tests. When the term cognitive ability test is used in a psychometric assessment context, it usually means all sorts of numerical reasoning, verbal reasoning, abstract reasoning, and mechanical reasoning tests. According to Hunter (1986), Cognitive ability tests are aimed at assessing person's abilities that are involved in thinking (e.g., reasoning, perception, memory, verbal and mathematical ability, and problem solving). The test items pose questions that are designed to estimate applicants' potential to the of use mental processes in solving work-related problems or to acquire new job knowledge.

Philip Carter is a UK IQ test expert who developed a standardized IQ test called Carter's Cognitive Abilities Test (Carter, 2007). The Carter's Cognitive Abilities Test (CogAT) is an Intelligence (Scholastic Aptitude) test with different levels and for different class levels. The CogAT has three different sections known as: Verbal Battery, Quantitative Battery, and Non-Verbal Battery. The Philip Carter's CogAT at secondary school level is aimed at testing mental abilities of students. The test includes Verbal, Quantitative, and Spatial subtests that are combined to provide a total score on students' total mental ability. CogAT at secondary level is used in the assessment of cognitive abilities of students in three cognition levels; basic, application, and critical thinking abilities using items on three test three subsets (verbal, quantitative, and spatial).

Tests as instruments for assessment may accurately or inaccurately reflect students' current level of learning. That is the reason a test needs to be studied from different angles and the items in the test be evaluated using test theories or models that can provide better perspective on the relationship that may exists between the observed score on a test and the underlying capability in the domain which is generally unobserved (Champlain, 2010). Classical Test Theory (CTT) and Latent Trait Theory (LTT) are two main test theories that test developers engaged in the development and evaluation test items performance. These two theories currently are popular measurement frameworks for identifying measurement problems such as test-score equating, test development and the identification of biased items.

The general CTT model is based on the notion that the observed score that test takers obtain from assessments is composed of a theoretical un-measurable "true score" and error. Just as most measurement devices have some error inherent in their measurement (e.g., a thermometer may be accurate to within 0.1 degree 9 times out of 10), so too do assessment scores. CTT simple summation of raw scores without considering differences between the items and information the pattern of response can provide most often lead to an inaccurate estimation of cognitive impairment (Wouters, 2008). Test items within a measure may differ in a number of ways. Therefore, there is a need to look beyond the total score and to investigate the pattern of response to the individual items. This can only be done with the use of 'Latent Trait Theory' (LTT) statistical method otherwise known as item response theory (IRT).

The quality of test items in any public examinations can be established through Latent Trait item analysis of examinees' responses. This process assesses the quality of test items and of the test as a whole by examining students' responses to individual test items. Traditionally, the proficiency of individual examinees is reported in terms of number-right scores (number of items answered correctly). One limitation or weakness with CTT approach, is that students with the same number-right score may have different response patterns (i.e., correct answers on different items) and, thus, may not have the same level of proficiency measured by the test. Reports related to the quality of test items, on the other side, are usually limited to indexes of *item difficulty* (proportion of correct answers on the item) and *item discrimination*. But a key problem with such indexes is that they depend on the group of examinees being tested and, therefore, do not adequately reflect the measurement quality of the test items. Hence the study engaged the use of IRT to examine the Philip Carter's CogAT parameters, how the items functioned differentially and the suitability of the test among junior secondary school students in Ondo State Nigeria. Philip Carter's Cognitive Abilities Test was purposefully selected for this study because of its correlation with English language and Mathematics which are two major core subjects at the Basic and Secondary school levels in Nigeria.

Differential item functioning (DIF) is a form of bias in test scores, whereby the probability of endorsing an item is higher for one group than the other, across various trait levels (Swaminathan & Rogers, 1990). In other words, despite two people from different groups having the same latent trait level, they have a different probability of obtaining a correct score on a given item. According to Yan Zhang (2015), Differential Item Functioning (DIF), as an assessment tool, has been widely used in healthcare, business management, and educational measurement. Assessment developers design and construct questionnaires or tests including sets of items that measure, for example, cognition, personality traits, or political views. DIF occurs if responders to a questionnaire or test item from different groups with the same overall scores have different probabilities of giving a correct or positive response to the item. Specifically, DIF has been recognized as a standard tool to measure significant item function differences across groups (e.g., gender or race) while controlling the overall scores on the trait being measured. The usual convention is to designate one group as the reference group (e.g., male, or white) and the others as focal groups (female, or African Americans, Asian Americans, etc.).

According to Odili (2010), he revealed that interest in analysis of differential item functioning in test derives from the consideration that education is perceived as instrument for achieving egalitarianism among persons and that ability is the quality of being able to do something. Hence, the recorded level of accomplishment an individual reaches is referred to as ability level. There is perhaps, no issue more visible among national examinations conducted in a heterogeneous country like Nigeria than differential item functioning (DIF).

In the consideration of the title of this study, the specific objectives were to:

1. Determine the test item that function differentially based on sex among the test takers.
2. Investigate the test item that function differentially based on school ownership among the test takers.
3. Assess Ondo State secondary school students' developing cognitive abilities.

Research Questions

1. Which of the test item functioned differentially based on sex among the test takers?
2. Which of the test item functioned differentially based on school location among the test takers?
3. Which of the test item functioned differentially based on school type among the test takers?

Methodology

Descriptive survey research design was adopted in the study. The study population comprised all the 37,752 Junior Secondary Three (JS III) students in Ondo State junior secondary schools during the 2019 academic session. The students' population during considered academic session consists of 18,804 male and 18,948 female. The study sample consisted of 1080 JS III students that were selected using the multistage sampling procedures. Three Local Government Areas (LGAs) were selected randomly from each senatorial district of the State and from each of the selected LGAs two junior secondary schools were selected randomly to make a total of 18 schools. A total of 60 JS III students were selected using non-proportional stratified random sampling technique with sex and school ownership serving as basis for the stratification.

The Philip Carter's Cognitive Ability Test (CogAT) was adopted as instrument for collecting relevant data for the study. The CogAT is a test of mental ability that includes Verbal, Quantitative, and Spatial subtests which are combined to provide a total score. The assessment of the DIF was done using Mantel-Haenszel DIF method of DIF assessment and the hypotheses were tested at the 0.05 level of significance.

Results

Research question 1: Which of the items of the Cognitive Abilities Test functioned differentially based on sex among the test takers?

To answer this research question, the responses of the students to the original cognitive abilities test was subjected to differential item functioning and the assessment of the DIF was done using Mantel-Haenszel DIF method of DIF assessment with the female students as the focal group. The result is presented in Table 1.

Table 1: Differential item functioning of Cognitive Abilities Test with respect to gender

Item	MH Stat	P-value	Remark	Item	MH Stat	P-value	Remark
SPAT1	1.564	0.211	NO DIF	VER6	1.500	0.221	NO DIF
SPAT2	31.059	0.000	DIF	VER7	10.996	0.001	DIF
SPAT3	6.924	0.009	DIF	VER8	18.043	0.000	DIF
SPAT4	8.002	0.005	DIF	VER9	0.795	0.373	NO DIF
SPAT5	1.669	0.196	NO DIF	VER10	0.015	0.901	NO DIF
SPAT6	39.850	0.000	DIF	NUM1	0.023	0.881	NO DIF
SPAT7	0.089	0.766	NO DIF	NUM2	1.674	0.196	NO DIF
SPAT8	34.432	0.000	DIF	NUM3	6.209	0.013	DIF
SPAT9	0.119	0.730	NO DIF	NUM4	0.016	0.900	NO DIF
SPAT10	0.791	0.374	NO DIF	NUM5	35.547	0.000	DIF
VER1	14.447	0.000	DIF	NUM6	2.821	0.093	NO DIF
VER2	0.015	0.902	NO DIF	NUM7	9.398	0.002	DIF
VER3	1.570	0.210	NO DIF	NUM8	0.391	0.532	NO DIF
VER4	1.349	0.246	NO DIF	NUM9	17.273	0.000	DIF
VER5	34.274	0.000	DIF	NUM10	9.050	0.003	DIF

Table 1 showed the differential functioning assessment of the cognitive abilities test items with respect to gender. The Table showed that out of the 10 items of spatial ability subcomponent of the cognitive test, five functioned differentially with respect to gender. They are SPAT2 (MH stat = 31.059, $p < 0.05$), SPAT3 (MH stat = 6.924, $p < 0.05$), SPAT4 (MH stat = 8.002, $p < 0.05$), SPAT6 (MH stat = 39.850, $p < 0.05$) and SPAT8 (MH stat = 34.432, $p < 0.05$). In the same vein, the Table showed that out of 10-item Verbal ability subcomponent of the cognitive abilities test, four items functioned differentially with respect gender. They are Ver1 (MH stat = 14.447, $p < 0.05$), Ver5 (MH stat = 34.274, $p < 0.05$), Ver7 (MH stat = 10.996, $p < 0.05$) and Ver8 (MH stat = 18.043, $p < 0.05$). Finally, the table showed that out of the 10-item numerical ability, five functioned differentially with respect to gender. They are NUM3 (MH stat = 6.209, $p < 0.05$), NUM5 (MH stat = 35.547, $p < 0.05$), NUM7 (MH stat = 9.398, $p < 0.05$), NUM9 (MH stat = 17.273, $p < 0.05$) and NUM9 (MH stat = 9.050, $p < 0.05$). The result showed that in all, 14 of the 30 items of the cognitive abilities test functioned differentially with respect to gender. The implication of the result is that 14 of the 30-items measured gender related construct other than cognitive abilities test.

Research question 2: Which of the test item functioned differentially based on school location among the test takers?

To answer this research question, the responses of the students to the original cognitive abilities test was subjected to differential item functioning and the assessment of the DIF was done using Mantel-Haenszel DIF method of DIF assessment with the students from rural schools as the focal group. The result is presented in Table 2.

Table 2: Differential Item Functioning of the Cognitive Abilities Test items with respect to school location

Item	Stat.	P-value	Remark	Item	Stat.	P-value	Remark
SPAT1	3.377	0.066	NO DIF	VER6	2.143	0.143	NO DIF
SPAT2	0.025	0.875	NO DIF	VER7	0.056	0.812	NO DIF

SPAT3	18.337	0.000	DIF	VER8	0.001	0.970	NO DIF
SPAT4	8.266	0.004	DIF	VER9	21.633	0.000	DIF
SPAT5	109.552	0.000	DIF	VER10	36.377	0.000	DIF
SPAT6	0.463	0.496	NO DIF	NUM1	2.162	0.142	NO DIF
SPAT7	0.320	0.572	NO DIF	NUM2	12.895	0.000	DIF
SPAT8	50.829	0.000	DIF	NUM3	11.911	0.001	DIF
SPAT9	0.038	0.846	NO DIF	NUM4	2.100	0.147	NO DIF
SPAT10	0.152	0.697	NO DIF	NUM5	5.297	0.021	DIF
VER1	59.004	0.000	DIF	NUM6	78.430	0.000	DIF
VER2	2.122	0.145	NO DIF	NUM7	5.457	0.020	DIF
VER3	3.123	0.077	NO DIF	NUM8	2.674	0.102	NO DIF
VER4	60.309	0.000	DIF	NUM9	7.821	0.005	DIF
VER5	14.831	0.000	DIF	NUM10	10.793	0.001	DIF

Table 2 showed the differential functioning assessment of the cognitive abilities test items with respect to school location. The table showed that out of the 10 items of spatial ability subcomponent of the cognitive test, four functioned differentially with respect to school location. They are SPAT3 (MH stat = 18.337, $p < 0.05$), SPAT4 (MH stat = 8.266, $p < 0.05$), SPAT5 (MH stat = 109.552, $p < 0.05$), and SPAT8 (MH stat = 50.829, $p < 0.05$). Furthermore, the table shows that out of 10-item Verbal ability subcomponent of the cognitive abilities test, five items functioned differentially with respect school location. They are Ver1 (MH stat = 59.004, $p < 0.05$), Ver4 (MH stat = 60.309, $p < 0.05$), Ver5 (MH stat = 14.831, $p < 0.05$), Ver9 (MH stat = 21.633, $p < 0.05$) and Ver10 (MH stat = 36.377, $p < 0.05$). Lastly, the table shows that out of the 10-item numerical ability, seven functioned differentially with respect to school location. They are NUM2 (MH stat = 12.895, $p < 0.05$), NUM3 (MH stat = 11.911, $p < 0.05$), NUM5 (MH stat = 5.297, $p < 0.05$), NUM6 (MH stat = 78.430, $p < 0.05$), NUM7 (MH stat = 5.457, $p < 0.05$), NUM9 (MH stat = 17.273, $p < 0.05$), and NUM9 (MH stat = 9.050, $p < 0.05$). The result showed that in all 16 of the 30 items of the cognitive abilities test functioned differentially with respect to school location. The implication of the result is that the cognitive abilities measured school location related construct other than cognitive abilities test.

Research question 3: Which of the test item functioned differentially based on school type among the test takers?

To answer this research question, the responses of the students to the original cognitive abilities test was subjected to differential item functioning and the assessment of the DIF was done using Mantel-Haenszel DIF method of DIF assessment with the students from public schools as the focal group. The result is presented in Table 3.

Table 3: Differential Item Functioning of Cognitive Abilities Test with respect to type of schools

Item	Stat.	P-value	Remark	Item	Stat.	P-value	Remark
SPAT1	16.869	0.000	DIF	VER6	6.756	0.009	DIF
SPAT2	7.622	0.006	DIF	VER7	23.174	0.000	DIF
SPAT3	0.345	0.557	NO DIF	VER8	181.185	0.000	DIF
SPAT4	0.229	0.633	NO DIF	VER9	114.057	0.000	DIF
SPAT5	0.053	0.819	NO DIF	VER10	0.001	0.979	NO DIF

SPAT6	9.928	0.002	DIF	NUM1	20.251	0.000	DIF
SPAT7	0.962	0.327	NO DIF	NUM2	0.044	0.834	NO DIF
SPAT8	12.382	0.000	DIF	NUM3	15.386	0.000	DIF
SPAT9	46.345	0.000	DIF	NUM4	13.779	0.000	DIF
SPAT10	3.713	0.054	NO DIF	NUM5	36.636	0.000	DIF
VER1	3.548	0.060	NO DIF	NUM6	176.182	0.000	DIF
VER2	93.480	0.000	DIF	NUM7	5.496	0.019	DIF
VER3	54.622	0.000	DIF	NUM8	11.198	0.001	DIF
VER4	93.615	0.000	DIF	NUM9	43.808	0.000	DIF
VER5	9.921	0.002	DIF	NUM10	28.661	0.000	DIF

Table 3 showed the differential functioning assessment of the cognitive abilities test items with respect to school type. The Table showed that out of the 10 items of spatial ability subcomponent of the cognitive test, four functioned differentially with respect to school type. They are SPAT1 (MH stat = 16.869, $p < 0.05$), SPAT2 (MH stat = 7.622, $p < 0.05$), SPAT6 (MH stat = 9.928, $p < 0.05$), SPAT8 (MH stat = 12.382, $p < 0.05$) and SPAT9 (MH stat = 46.345, $p < 0.05$). Furthermore, the table shows that out of 10-item Verbal ability subcomponent of the cognitive abilities test, only two did not function differentially with respective school type, the remaining eight items functioned differentially with respect school type. The eight items are Ver2, ver3, ver4, ver5, ver6, ver7, and ver8. Lastly, the table shows that out of the 10-item numerical ability, all except NUM1 functioned differentially with respect to school type. They are NUM1, NUM3, NUM4, NUM5, NUM6, NUM7, NUM8 and NUM9 and NUM10 (MH stat = 12.895, $p < 0.05$), NUM3 (MH stat = 11.911, $p < 0.05$), NUM5 (MH stat = 5.297, $p < 0.05$), NUM6 (MH stat = 78.430, $p < 0.05$), NUM7 (MH stat = 5.457, $p < 0.05$), NUM9 (MH stat = 17.273, $p < 0.05$), and NUM9 (MH stat = 9.050, $p < 0.05$). The result showed that in all 22 of the 30 items of the cognitive abilities test functioned differentially with respect to school type. The implication of the result is that the cognitive abilities measured school type related construct other than cognitive abilities test.

Discussion of Finding

Camilli and Shepard (1994), cited by Wu and Ercikan (2006), define DIF as a statistical procedure that checks whether examinees with comparable total test scores belonging to different groups answer similarly the individual items of the test. In a more general way, DIF refers to differences in psychometric properties of the items between groups (Fidalgo, 1996). In conducting DIF analyses it is usual that there are, at least, two groups of interest: the focal group and the reference group. The former generally refers to a minority or traditionally considered disadvantaged group, while the latter is the majority or privileged group. To identify which of the items functioned differentially based on sex among the test takers the original cognitive abilities test was subjected to differential item functioning and the assessment of the DIF was done using Mantel-Haenszel DIF method of DIF assessment with the female students as the focal group. In all 14 of the 30 items of the cognitive abilities test functioned differentially with respect to gender, that is, 14 of the 30-items measured gender related construct other than cognitive abilities test. Again, 16 of the 30 items of the cognitive abilities test functioned differentially with respect to school location meaning that the cognitive abilities measured school location related construct other than cognitive abilities test. Also, 22 of the 30 items of the cognitive abilities test functioned differentially with respect to school type which means that the cognitive abilities measured school type related construct other than cognitive abilities test.

The implication of these findings is that in the context of junior secondary school students of Ondo State, Nigeria, the Philip Carter's Cognitive Ability Test (CogAT) items apart from measuring and determining the cognitive ability level of the students as a sole responsibility of the items, students' interaction with and response to some of the items is dependent on their sex, school type and school location which are constructs outside of the cognitive ability. It thus means that in the use of the CogAT among junior secondary school students and Nigeria at large, users need to take note of how students interact with and the pattern of response to the items. This will guide in the interpretation of the results and discussion to be reached based on the result.

Conclusion and Recommendation

The study therefore concluded that to use the Philip Carter's Cognitive Abilities Test in the measurement junior secondary school students' cognitive ability in Ondo State and Nigeria at large, there is the need for trial testing and thorough analysis of the item's psychometric parameters among Nigerian junior school students through which items that are suitable for use among students in Nigerian junior school will be identified. The study therefore recommends that an adapted version Philip Carter's CogAT be generated for use in measuring students' cognitive ability among the junior secondary school students in Nigeria.

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