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Article

Evaluation of Differential Distractor Functioning of Physics Achievement Battery for Quality Assurance Using Multinomial Log-linear Model

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Abstract: School examinations including Physics have been fraught with biased questions. Equality in the nature of examination questions is not attained between focal and reference test-takers. This makes assessment of the learners' knowledge of subject content, no matter the instructional strategy deployed a mirage. This study therefore is an attempt to produce a psychometrically gender-neutral Physics achievement test, using differential distractor functioning approach. Ex-post-facto was the design adopted. A sample of 153 senior secondary school Physics students was determined through random sampling with replacement from Uzo-Uwani Local Government Area of Enugu State. Dichotomously scored Physics achievement test (PAT) with high face and content validities was the instrument used. The internal consistency of PAT using Kuder-Richardson's formular-21 was .71. Data were analyzed using multinomial log-linear procedure in r.3.4.3. The result indicated that out of sixty items presented for calibration, fifty-one of them fit multinomial log-linear model. It was recommended that the fifty-one valid items should be used for school Physics examination.

Keywords: Differential distractor functioning, quality assurance and Physics achievement.

1. Introduction

The place of Physics for the development of any society can hardly be over-emphasized. In electronic circuits including radio, television and computers for example, continuously varying direct and alternating current signals ar**e** processed by the devises' internal elements including the transistor. The transistor is one of the prominent circuit elements which is used to attenuate and amplify the signals to the desired form. The wonderful circuit element called transistor contains three pins: emitter, collector and base which are submerged within one body. The signals refer to the waves sourced from inputs like light and sound coming into the electric circuit which are converted into current and voltage forms with their associated frequencies within the whole or part of the circuit. The electric current flowing in any given part of a circuit or the voltage differentials across two points in an electric circuit can be altered by parallel or series arrangement of some circuit elements including resistor, capacitor and inductor in conjunction with a transistor. In advanced electrical and electronics designs, many transistors and other circuit elements that are made of semi-conducting material are combined in a certain order to form a logic gate or an integrated circuit, fondly referred to as 'IC' (Nelkon & Parker, 1995). The IC is also referred to as operational amplifier (opamp), which consists of three pins: the non-inverting input, inverting input and an output pin. The non-inverting input is a positive terminal whereas the inverting input is the negative terminal. The beauty of opamp circuits lies in its ability to produce a high amplitude wave signal relative to its input. The signal can be inverted or non-inverted depending on what forms the input with the zero-voltage-earth of the opamp. For simple amplifier, the input terminal of the opamp is the positive terminal and the zero-voltage-earth infused with the negative terminal, the amplifier becomes non-inverting type. The reverse is the case for an inverting amplifier. Moreover, the determinant in producing non-inverting or an inverting amplifier is hinged on the purpose it is meant to serve. In the entertainment industry, where a large sound is needed to be given to a large audience, the non–inverting opamp circuit is used to provide signals to the loud speakers. The communication industry is also a benefactor of the non-inverting opamp circuit. The cell phones and computers used in long distance communication use this technology. Effective communication using digital devises promotes a virile market structures and the economy of any nation. However, the inverting opamp is applied in astronomical telescopes and cameras where the inverted images produced in these devises are inverted to upright final images. Telescopes are used for space exploration in addition to sending signals to satellites lunched in a weightless orbit. Also, amplifier with resistors and capacitors are used to produce an electrical gadget called multi-vibrator, which emits ultrasonic frequencies which can be used to checkmate the growth of harmful bacteria in water.

Another practical application of amplifier combined with other circuit elements including resistors and capacitor is in the construction of switching circuits in electronic devices. Switching circuit is an electronic arrangement that is used to automatically put a circuit 'on' or 'off'. Switching circuits are used for rocket lunching. The impact of rocket, missile or satellite lunching is synonymous with development of any economy. Lunched satellite apart from being used for communication purposes can be used for weather forecast. It can also be used to enhance military surveillance for peace-keeping operations in troubled spots around the world. It is also applied in the construction of burglar alarms and street lights. Street lights are designed to be automatically 'off' during the day and 'on' at dusk.

By and large, the working of an integrated circuit or logic gates in electrical and electronic systems is used to solve the problems of mankind depend on the principles of Physics. The inclusion of Physics as a school subject becomes paramount, in the light of its benefits to the society. In this direction, the Federal Government of Nigeria (FGN, 2013) through the Federal Ministry of Education restated the importance of inclusion of Physics as a subject to be studied in senior secondary education under Science and Mathematics sub-heading. Physics Education researchers including Nnadi and Anamezie (2018) also noted that the reason for inclusion of Physics as a school subject is to make students become adaptive to ever-dynamic science and technological age. The knowledge and practice of the principles of Physics can help the students to become self-reliant. Unfortunately, the achievement level of secondary school students in Physics, particularly in external examinations conducted by National Examination Council (NECO), West African Examinations Council (WAEC) and National Business and Technical Examinations Board (NABTEB) has remained consistently poor over the years (WAEC Chief Examiners' report, 2017; Odunsi, 2018 and NABTEB, 2018). The poor state of students' achievement in Physics has constituted a source of worry to the stakeholders in the education industry. The use of examination questions of poor psychometric quality especially by the Physics teachers and sometimes by the external examination bodies in assessing the ability levels of their students has partly been linked to defective determination of the true abilities of the students for the purposes of placement and certification (Nworgu, 2016). The common practice among Nigerian Physics teachers is to set their teacher-made questions and use same to evaluate their students at the formative level. Such tests are usually set in a hurry and most importantly the teachers lack the know-how on test standardization. Test experts including Owolabi, Onuka, Ogunjimi, Mustapha, Adaramaja and Daramola (2017) have reported that teacher-made tests are unstandardized and their use to determine students' grades are unreliable. The attendant consequence of misplacement of students' final grades also includes the allocation of the wrong set of students to study Physics or Physics related courses in the tertiary institutions of learning. At the classroom level, Physics teachers use teacher made-tests for continuous assessment (kick-off test, assignment, mid-term test and examination). The efforts of the Enugu state government in harmonizing end-of-year examinations for all schools is quite commendable, since 2017 but the first and second term examinations are left for the teachers to organize. There is the need for high quality examination questions (Physics included) that should be used for both internal and external examinations, bearing in mind that test items should be fair to the sub-groups which are nested within test takers' main group. This observation is in tandem with a statutory document of the Federal Government of Nigeria, through the Federal Ministry of Education's (2015) national education quality assurance handbook for basic and secondary education in Nigeria.

The Physics achievement test consists of a collection of different topics drawn from the various branches of Physics to form a battery of questions used by the Physics teachers for students' latent trait assessment. Part of what makes the Physics achievement battery made by Physics teachers or any examination body unfair, appears to be the omission of the measurement of the differential distractor functioning (DDF). DDF is an analysis procedure that is used to determine whether different distractors (incorrect option choices) attract various sub-groups of test takers differently (Green, Crone & Folk, 1989). The idea of DDF is contrary to commonly held views of some researchers including Olatunji (2007) and Owolabi et al, (2017) who reported in their separate studies that a distractor should be considered effective if at least 5% of the test takers selected it. The reason is because a distractor which functions differentially across the test takers' sub-groups and equally attracts at least 5% of test takers is not a fair distractor. Such a distractor favours a particular sub-group and marginalizes the other sub-group in selecting the correct option. Each sub-group represents the reference and the focal categorical sub-group. The focal group is usually the disadvantaged group. Any distractor that attracts the reference and focal sub-groups differently has a significant DDF and should be discarded or reframed until point of balance is attained. Also, Kyndra and Cara (2007) observed that the result of DDF analysis allows test developers to determine which items may need further observation. Mellenbergh (1982) also noted that log-linear model fitting provided the most parsimonious model and it also distinguished between items that were uniformly and non-uniformly biased. Uniform differential item functioning occurs when DIF is caused by difference in difficulty or discrimination (i.e., uniform or non-uniform) (Drabinova, & Martinkova 2016). The distractors may provide a possible reason why a particular test item exhibits differential item functioning (DIF). DIF analysis is a measure to determine if a test item functions differently across reference and focal categorical groups. Sometimes significant DDF options may cause DIF. In addition, DDF analysis is helpful to test developers because it gives information on a particular distractors' inclination to the sub-groups. It is important to note that both DIF and DDF represents different concept. This is because an item may not have a significant DIF, but can have significant DDF. This observation is in line with the observation earlier made by Koon (2010).

DDF analysis can be performed using a variety of methods including multinomial log-linear model. This technique infused both the multinomial logistic regression model proposed by Kato, Moen and Thurlow (2009) and log-linear analysis model proposed by Green, Crone and Folk (1989).

Therefore, the multinomial log-linear model is a hybridized model. The model estimates a response characteristic curve (RCC) of the probability of the answer against standardized total score, representing the ability level (z) for each response option (j) (Kato et al). The slope factor (b_j) represents the correct option, which is usually the RCC with a sigmoid 'S' shape. The intercept (a_j) represents the popularity of the response options. Larger value of the intercept indicates that the response option is chose more frequently relative to others. The hybrid model is advantageous because it analyzes incorrect responses options, main effect (ability groups), interaction of DDF index and ability group, slope factor and intercept (relative popularity of distractor). More importantly, it computes the likelihood ratio Chi-square value, probability (p) value and the significance codes for flagging down items as having significant DDF based on the alpha value proposed for the model.

1.1. Purpose of the Study

The purpose of the study was to evaluate the differential distractor functioning of Physics achievement battery for quality assurance using multinomial log-linear model. Specifically, the study sought to determine:

a) The calibrated estimates of Physics achievement battery based on the differential distractor functioning
b) How many items of the Physics achievement battery have significant differential distractor functioning.
c) What made the significant items to function differentially

1.2. Research Questions

The following research questions guided the study:

a) What are the calibrated estimates of Physics achievement battery based on the differential distractor functioning?
b) How many items of the Physics achievement battery have significant differential distractor functioning?
c) What made the significant items to function differentially across male and female sub-groups?

2. Method

The study utilized ex-post facto research design. The experimenters did not manipulate the variables of the study, instead they used them as they occurred in their natural states. The population for the study comprised four thousand, two hundred and forty six senior secondary three Physics students nested within 56 public secondary schools in Uzo-Uwani (Ministry of Education Enugu, 2010). The sample for the study consisted of 153 SS3 Physics students from Uzo-Uwani Local Government Area. The sample consisted of eight four (84) female SS 3 Physics students and sixty nine (69) male students. Simple random sampling, specifically balloting with replacement was used to sample five schools in the area. Simple random sampling was also used to select intact classes used for the study. The instrument used to collect data was Physics achievement test (PAT). PAT, which was drawn from the five areas of the Physics curriculum in Nigeria, was developed by the researchers. PAT originally comprised 75 dichotomously scored items with four options. The content validity of PAT was achieved using Table of specifications, measuring knowledge, comprehension and application levels of Bloom's taxonomy of educational objectives. PAT was subjected to face validation by Physics Education experts in the Department of Science and Computer Education, Enugu State University of Science and Technology, in terms of clarity and adequacy of the items in addressing the problems of the study. Fifteen items of PAT failed the face validity test. The sixty items that survived face validation were subjected to differential distractor functioning calibration, using multinomial log-linear model. The item analysis was implemented using differential distractor functioning using non-linear regression model (difNLR version 1.1.1) package in open source r software, version 3.4.3. The internal consistency reliability of PAT determined using Kuder-Richarson's formula-21 on a parallel sample was .71, since the items were dichotomously scored. Prior to calibration, the collected dichotomous data were first used to test the uni-dimensionality assumption of item response theory (IRT). The scree plot showed the presence of one latent construct (ability) for all the items. The collected data were finally analyzed using multinomial log-linear procedure in r 3.4.3 via R-studio version 1.0.153. The condition for accepting an item as having a significant differential distractor functioning was if it had a probability value less than .05 (Guyer & Thompson, 2014; Drabinova & Martinkova 2016). Any distractor of a differentially functioning item whose group statistics is above one favors the focal sub-group (female) whereas any distractor of a differentially functioning item whose group statistics is less than one favors the reference sub-group (male) (Koon,2010).

3. Results

3.1. Research Question 1

What are the calibrated estimates of Physics achievement battery based on the differential distractor functioning?

The results in Table 1 shows the chi-square and probability values for each item in the Physics test.

Table 1: Item Chi-square and p values

Item	Chisq value	P value	Item	Chisq value	P value	Item	Chisq value	P value
Q1	13.5428	0.0352*	**Q21**	14.8636	0.0619	**Q41**	7.8421	0.2499
Q2	10.0746	0.1215	**Q22**	8.8438	0.1826	**Q42**	15.1701	0.0190*
Q3	4.5821	0.5984	**Q23**	4.5821	0.5984	**Q43**	13.7548	0.0325*
Q4	5.9289	0.4312	**Q24**	5.9289	0.4312	**Q44**	8.9934	0.1740
Q5	4.3098	0.6348	**Q25**	4.2393	0.6443	**Q45**	3.9524	0.6831
Q6	10.5419	0.1036	**Q26**	12.5247	0.0512	**Q46**	11.8679	0.0650
Q7	8.4325	0.2081	**Q27**	8.4325	0.2081	**Q47**	3.7662	0.7083
Q8	1.8442	0.9335	**Q28**	2.6579	0.8504	**Q48**	14.0026	0.0296*
Q9	14.2392	0.0271*	**Q29**	14.2386	0.0271*	**Q49**	7.5074	0.2765
Q10	8.0063	0.2376	**Q30**	8.0063	0.2376	**Q50**	10.3931	0.1090
Q11	7.8421	0.2499	**Q31**	7.8421	0.2499	**Q51**	6.7781	0.3419
Q12	11.8196	0.0661	**Q32**	11.8196	0.0661	**Q52**	2.1605	0.9044
Q13	6.8244	0.3374	**Q33**	6.8244	0.3374	**Q53**	5.5818	0.4716
Q14	8.9934	0.1740	**Q34**	8.9934	0.1740	**Q54**	6.1833	0.4030
Q15	3.1712	0.7871	**Q35**	3.1712	0.7871	**Q55**	6.2219	0.3988
Q16	11.8679	0.0650	**Q36**	11.8679	0.0650	**Q56**	6.0173	0.4213
Q17	2.3964	0.8799	**Q37**	2.3964	0.8799	**Q57**	6.8734	0.3327
Q18	14.0026	0.0296*	**Q38**	14.0022	0.0296*	**Q58**	9.3604	0.1543
Q19	7.5074	0.2765	**Q39**	7.5074	0.2765	**Q59**	13.1880	0.0401*
Q20	10.3931	0.1090	**Q40**	10.3931	0.1090	**Q60**	1.4116	0.9652

The chi-square values for the 60 items ranged between 1.4116 and 15.1701 while their probability values ranged from .0190 to .9652. The number of items whose p values is less than .05 is seven. They included Q1(.0352), Q9(.0271), Q18(.0296), Q29(.0271), Q38(.0296), Q42(.0190), Q43(.0325), Q48(.0296) and Q59(.0401). All the other forty-one items had their estimated probability values above 0.05. So they fit into the multinomial log-linear model.

3.2. Research Question 2

How many items of the Physics achievement battery have significant differential distractor functioning?

Table 2 below shows that nine items in the Physics achievement test (Q1, Q9, Q18, Q29, Q38, Q42, Q43, Q48 and Q59) were not selected for inclusion in the final Physics achievement test on the ground of having p values less than .05 whereas the rest of the items were selected.

Table 2: Table of selected items

Item	P value	Remarks	Item	P value	Remarks	Item	P value	Remarks
Q1	0.0352*	**NS**	**Q21**	0.0619	**S**	**Q41**	0.2499	**S**
Q2	0.1215	**S**	**Q22**	0.1826	**S**	**Q42**	0.0190*	**NS**
Q3	0.5984	**S**	**Q23**	0.5984	**S**	**Q43**	0.0325*	**NS**
Q4	0.4312	**S**	**Q24**	0.4312	**S**	**Q44**	0.1740	**S**
Q5	0.6348	**S**	**Q25**	0.6443	**S**	**Q45**	0.6831	**S**
Q6	0.1036	**S**	**Q26**	0.0512	**S**	**Q46**	0.0650	**S**
Q7	0.2081	**S**	**Q27**	0.2081	**S**	**Q47**	0.7083	**S**
Q8	0.9335	**S**	**Q28**	0.8504	**S**	**Q48**	0.0296*	**NS**
Q9	0.0271*	**NS**	**Q29**	0.0271*	**NS**	**Q49**	0.2765	**S**
Q10	0.2376	**S**	**Q30**	0.2376	**S**	**Q50**	0.1090	**S**
Q11	0.2499	**S**	**Q31**	0.2499	**S**	**Q51**	0.3419	**S**
Q12	0.0661	**S**	**Q32**	0.0661	**S**	**Q52**	0.9044	**S**
Q13	0.3374	**S**	**Q33**	0.3374	**S**	**Q53**	0.4716	**S**
Q14	0.1740	**S**	**Q34**	0.1740	**S**	**Q54**	0.4030	**S**
Q15	0.7871	**S**	**Q35**	0.7871	**S**	**Q55**	0.3988	**S**
Q16	0.0650	**S**	**Q36**	0.0650	**S**	**Q56**	0.4213	**S**
Q17	0.8799	**S**	**Q37**	0.8799	**S**	**Q57**	0.3327	**S**
Q18	0.0296*	**NS**	**Q38**	0.0296*	**NS**	**Q58**	0.1543	**S**
Q19	0.2765	**S**	**Q39**	0.2765	**S**	**Q59**	0.0401*	**NS**
Q20	0.1090	**S**	**Q40**	0.1090	**S**	**Q60**	0.9652	**S**

Key: S-Selected, **NS**-Not Selected

Therefore, nine items of the Physics achievement test did not fit into the multinomial log-linear model while forty-one items fit into the model.

3.3. Research Question 3

What made the significant items to function differentially across male and female sub-groups?

Table 3 below shows the intercept and group statistics for the items with their corresponding dis tracters which did not fit into the multinomial log-linear model.

Table 3: Distractor statistics for misfit items

DIF Item	DISTRACTORS		
	INTERCEPT	**GROUP**	**DESCRIPTION**
Q1	**A:**-0.8907372	2.012948	Favored focal group (female)
	C:-0.9073153	1.661282	Favored focal group (female)
	D:-0.5016892	-20.670923	Favored reference group (male)
Q9	**A:** 0.4467545	-66.691853	Favored reference group (male)
	C: -0.8122513	1.784670	Favored focal group (female)
	D: 0.3208041	1.186909	Favored focal group (female)
Q18	**B:** 1.0968591	0.1363444	Favored reference group (male)
	C: 0.2471535	-11.2766429	Favored reference group (male)
	D: -0.1546157	2.4867643	Favored focal group (female)
Q29	**A:** 1.2593277	-67.7493672	Favored reference group (male)
	B: 0.8110246	-1.7820803	Favored reference group (male)
	D: 1.1323871	-0.5968677	Favored reference group (male)
Q38	**A:** -1.0966004	-0.1390876	Favored reference group (male)
	C: -0.8497553	-8.4316334	Favored reference group (male)
	D: -1.2513637	2.3501185	Favored focal group (female)
Q42	**A:** 14.14095	-14.10333	Favored reference group (male)
	C: 14.55984	-16.23713	Favored reference group (male)
	D: 13.29566	-12.71042	Favored reference group (male)
Q43	**B:** 0.4443199	-0.3130687	Favored reference group (male)
	C: -0.6649234	1.4520432	Favored focal group (female)
	D: -0.3667485	-89.3884407	Favored reference group (male)
Q48	**B:** 1.0968591	0.13634	Favored reference group (male)
	C: 0.2471535	-11.2766429	Favored reference group (male)
	D: -0.1546157	2.4867643	Favored focal group (female)
Q59	**A:** 0.5254775	0.5086074	Favored reference group (male)
	B: 0.5501469	-9.7437094	Favored reference group (male)
	C: -0.3660825	0.9261059	Favored reference group (male)

The intercept measures the relative popularity of each of the response options, with larger mean values indicating that the response option had higher frequency of being chosen by the test takers. For Q1, the decreasing order of the frequency of choice of the distracting options were D, A and C respectively. For the group mean of Q1, distractor A, C and D had 2.012948, 1.661282 and -20.670923 respectively. Using the criteria set for this study, options A and C had group mean above one and therefore favoured the focal group (female). Option D had a group mean of -20.670923 and being less than one fovoured the reference group (male). The popularity of the distractors among the test takers in descending order for Q9 included A, D and C respectively. While a favoured male sub-group, options D and C favoured the female sub-group. Options B and C favoured male sub-group, while D favoured the female sub-group for Q18. In Q29, all the distractors favoured a particular group, the male sub-group. For Q38, A and C favoured male sub-group while D favoured the female sub-group. For Q42, al the distractors favoured only male sub-group. In Q43, distractor B and D favoured male sub-group while C favoured the female sub-group. In Q48, B and C favoured male sub-group while D favoured the female sub-group. The most popular option in Q59 was B followed by A and the least was C. All the distracters in Q59 favoured male sub-group.

Fifty-one items out of sixty calibrated items had their probability values greater than .05. This is an indication that they did not vary significantly across the focal and reference sub-groups in the study. Forty-one items fit the multinomial log-linear model while nine items had a misfit. The calibrated items followed the procedure adopted by …The response characteristic curve for sample of items (Q2, Q6 and Q7) that fitted the model shown on Appendix A were clear and distinct. The four response curves were clearly plotted. The curve that has the highest 'S' elongation represented the key/correct option (Koon, 2010). The options' curves were squashed or took the shape of an 'S' curve. However, in Appendix A, items Q1 and Q9 which did not fit into the model were cloudy. This provides visual evidence that the options for the item varied significantly across focal and reference sub-groups. Thus upholding the monotonicity assumption of item response theory (Isiugo-Abanihe, Ilesanmi & Iluobe, 2017). For the items that did not fit the model including Q1 and Q9, their item response curves were cloudy. The popularity indices of the distractors which did not fit the model ranged from negative values to positive values. Options with negative popularity indices were not functional. This is in tandem with the recommendations of Owolabi et al (2017). Though, the wrong options attracted less than 5% of the test takers they were not functional. Some of the distracting options attracted above 15% of the test takers, but functioned differentially across the sub-groups.

4. Conclusion

The result of the study showed that fifty-one items of Physics achievement battery fit into the multinomial log-linear model, whereas nine items had a misfit. It was recommended that Physics teachers should use the result of this study to evaluate their students' achievement. Moreover, researchers in Physics Education who develop achievement tests should utilize the procedure to validate their multiple choice items.

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