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APPLICATION OF COGNITIVE DIAGNOSTIC MODEL IN ASSESSMENT OF BASIC ELECTRICITY PRACTICAL SKILLS PROFICIENCY AMONG PHYSICS EDUCATION UNDERGRADUATES IN ENUGU STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY

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ABSTRACT: *Generalized deterministic input noisy and gate (GDINA) model is a sub-set of cognitive diagnostic model which is used for item calibration and diagnosis. The use of GDINA for measurement of skills or concepts mastery has been synonymous with multiple-choice items. This study applied the GDINA model for mastery measurement of basic hierarchical Physics practical skills. The data collected and the final skills' matrix were analyzed using GDINA package version 1.4.2 in open source R software version 3.4.3 via R-Studio version 1.0.153. The results showed that: (i) the undergraduates exhibited a fairly good mastery of the items in the test. (ii) the skill of manipulating the voltage source needed improvement.(iii) the items in the test fit the GDINA model. It was recommended that Physics Education lecturers should spend more of their instructional time to practical in lieu of theory to further boost the undergraduates' skill/item mastery level in Physics.*

KEYWORDS: Physics, practical skills, hierarchy, GDINA model, calibration and diagnosis.

INTRODUCTION

It is a common observation within the classroom setting that students exhibit varying intellectual and practical abilities. Consequent upon the observed variation, the need therefore arises that every classroom teacher should have a better understanding of the degree of concept mastery by students during and after an instructional process. Teachers' proper understanding of the degree of students' concept or skill mastery is a necessity towards planning future lessons. It is a common practice among Nigerian classroom teachers that after an instructional process, which usually ended up in formative evaluation, teachers do not diagnose the concepts or skills mastery profile of the students. What is usually a common practice among the teachers is that corrections are given to the students at the end of evaluation as an antidote to concepts or skills mastery by all the students. In addition, the teacher switches to the next topic in subsequent instruction with a vague knowledge of the degree of students' concepts attainment in the previous lesson. This kind of instructional strategy does not favour students with below average working memory. Students who had low or moderate concept mastery and who needed additional instructional time to ensure a reasonable shift in their concept mastery status were usually abandoned by the teacher. In support of the existence of students with above and below average working memories, Mbajiorgu, Reid and Ezeano (2017) noted that the conditions for classroom instruction should be arranged to minimize any advantage for those with high working memory capacities. The reason for the minimization of differences in achievement of any advantaged group over the disadvantaged group by using fair test should be to reduce instructional biases and to provide equitable opportunities for all students irrespective of demographic or genetic variations.

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The failure on the part of the teachers to diagnose the degree of concepts or skills mastery and use the result from such cognitive diagnosis is seen as a cog in the wheel of instructional progress. To carter for the variation in students' abilities while probing into their cognitive structures, Ann (2013) reported that de la Torre in 2011 introduced the generalized deterministic input, noisy and gate (GDINA) model, in which students exhibiting different sets of required skills had different probabilities of mastering item j. Also, an examinee who possesses a greater proportion of the needed skills relative to another examinee may not necessarily have higher probability of success for an item. This could be attributed to individual carelessness level and item or skill slipperiness.

Instead of assuming that all examinees lacking at least one skill per item have same probability of correctly scoring the item no matter the degree of its mastery as does the deterministic input, noisy and gate (DINA) model, the GDINA is founded on the assumption that different latent groups, in terms of skills mastery have different probabilities of correctly responding to an item j. Ann also indicated that the use of GDINA was appropriate when working with dichotomous data and skills. In a GDINA framework, the marginal maximum likelihood method with expectation maximization algorithm is used for extraction of both item and skill profiles (R core team, 2015).

The role of family members of cognitive diagnostic models (CDM), including GDINA in continuous assessment of both test and learners' outcomes cannot be over-emphasized. At the item level, GDINA is proficient in providing the attribute structures of test items like the difficulty, discriminating, guessing and slipping or carelessness indices when the q-matrix is hierarchical. Anamezie and Nnadi (2018) indicated that q-matrix was an array of item by skill or concept matrix with the code "1" indicating the presence of a given skill needed for mastering an item j or code "0" for non-mastery. The possession of such skills and their correct application helps learners to be proficient in Physics practical. Moreover, a hierarchical q-matrix is such an item by skill or concept matrix where there can be more than one skill that are required for the mastery of an item. In a hierarchical q-matrix, mastery of one skill or concept is a prerequisite for mastery of another. The skills have nested structures. Linear hierarchical attribute structure with a loop formed the basic Electricity skills utilized in this study. From Table 1, skill 1 is a prerequisite for skill 2. Skill 2 is a prerequisite for skill 3. Skill 3 is a prerequisite for skill 4. Skill 4 is a prerequisite for skill 5. Skill 5 is a prerequisite for skill 6. Skill 6 is looped to skill 3 via skill7. Skill 6 is a prerequisite for skill 8. Skill 8 is a prerequisite for skill 9 while Skill 9 is a prerequisite for skill 10. In a linear hierarchy, (Yu-Lan, Won-Chan & Kyong, 2013) noted for instance that an examinee who mastered skill 8, must have mastered skills 1 through 7 as well. Furthermore at person level, GDINA provides information on the proportion correct per item, which indicates the proportion of the examinees that provided the correct response per item (Kyong, Young-Sun & Yoon, 2015). The proportion correct per item indicates the probability of mastery of each of the items by the examinees. The number of possible latent ability groups among the examinees is also modeled.

Within the GDINA framework, Huacheng (2016) reported that the intercept term, main and interaction effects were modeled. The intercept term represents the correct response probability to an item or skill when an examinee has not mastered an attribute that is needed for an item. de_la_Torre and Minchen (2014) defined intercept term as the baseline success probability when no required attribute were present. The correct item or skill can be chosen or applied as the case may be without mastery. Thus, it gives credence to chance. The intercept term represents guessing parameter. Skill guessing is a situation when there is no correct application

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of a skill. For example, if an experimenter is asked to tightly close an electric circuit key, and she/he closes the key loosely, it does not show mastery of the skill and this may affect the correctness of circuit readings due to partial contact. The consequence of this kind of error leads the experimenter to incorrect determination of the goal of the experiment. In addition, de_la_Torre and Minchen (2014) also indicated that while main effect was the change in success probability when one skill is mastered, interaction effect was the change in success probability when more than one skill is simultaneously mastered. Also, GDINA models slipping or guessing parameters. Whereas slipping parameter of the skills occur when an experimenter has mastered the requisite skills for a task, but due to fatigue or carelessness fails to appropriately carry it out, guessing is the correct application of a skill due without possessing the requisite skill. Guessing occurs as a result of chance factor.

The GDINA model provides a gate-way to other CDM sub-models' implementation including deterministic input, noisy and gate (DINA), deterministic input, noisy or gate (DINO), linear logistic model (LLM) and reduced re-parameterized unified model (RRUM). Ann (2013) noted that by setting parameter constraints and link functions (identity link function, logit and loglink), GDINA could be transformed to any of the sub models of CDM.

The effectiveness of GDINA model in providing better model fit relative to other sub-models of CDM has been documented. In a study conducted by Yamaguchi and Okada (2018) in Japan on the relative effectiveness of IRT and CDM sub-models in seven selected oversea countries indicated that the GDINA had a better model fit relative to all CDM and IRT sub-models. The model fit was measured using deviance information criterion (DIC) value. GDINA recorded the least value of DIC among other sub-models in all the countries tested. However, in Yamaguchi et al's study TIMSS 2007 Mathematics achievement was examined using CDM and IRT sub-models. No skill was modeled. There appears to be dearth of studies on skills mastery using GDINA.

The need for the use of GDINA model for calibration and diagnosis of basic Electricity skills of undergraduates becomes paramount in the light of the importance of Electricity to civilization. Electricity is one of the branches of Physics. It can be static or current electricity. Whereas static electricity is the electricity generated from positively or negatively charged bodies, current electricity is the flow of electrons through conducting loop. An electron is a negatively charged constituent of matter. Before electron-drift through electrical loop takes place, there has to be a source of force, referred to as Electromotive force (EMF) which should provide the pushing force for the already existing electrons in a conducting loop. As the electrons in the conductor move in the loop, current electricity moves. The electric current that moves in an electric circuit can either be direct or alternating current, depending on the mode of its propagation. Direct current electricity can chiefly be sourced from non-rechargeable chemical cells like dry batteries. Dry batteries are used to provide intermittent illuminations in the dark. Secondly, an alternating current can be transformed to a direct current by changing the rings of an alternator from slip to split rings. Furthermore, the importance of an alternating current for industrial revolution can hardly be overemphasized. Industrial machines including computers, telecommunication devices, x-ray machines, cars, airplanes and so on require alternating current to function. Due to the relevance of electricity, its study in post-primary schools is nested in Physics, Applied Electricity and Electronics especially in Nigeria. One of the reasons for studying electricity in three subjects in Nigeria is adduced to its importance. At the Senior School Certificate Examinations (SSCE) level, question on electricity in Physics practical is a yearly recurring decimal. The yearly choice of current electricity for testing

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Nigerian students' practical skills in Physics at SSCE level by National Examinations Council (NECO) and West African Examinations Council (WAEC) further authenticates the importance of electricity to mankind. Unfortunately, SSCE students who chose electricity in their Physics practical (Physics 3) examination in NECO and WAEC examinations have been reported to have challenges in some skills including assigning wrong units to certain physical quantities like current and voltage, wrong graphing to the accuracy of the chosen scales and the inability of the candidates to record inverse of current and voltages to at least three decimal places (WAEC resume of the Chief Examiner's report, n,d). To reverse students' challenging electrical skills the researchers reasoned that it would be proper to diagnose basic electricity skills possessed by student-teachers of Physics using GDINA model. This is because no quality of education can rise above the quality of its teachers. Poor quality of educational output can be corrected at the level of teacher-training.

Purpose of the Study

The study intended to: (i) determine the probability of correct response of the basic electricity items. (ii) determine the probability of guessing the basic electricity skills (iii) determine the slipping with guessing parameters of the practical test items.

Research Questions

Three research questions guided the study. They included: (i). What is the probability of correct response of the basic electricity items? (ii). What is the probability of guessing the basic electricity skills? (iii). What are the slipping with guessing parameters of the practical test items?

Research Method

The study adopted a mixed research design. Firstly, pure experimental design was adopted in setting up electric circuit and manipulating the voltage source in the electrical loop to get the required values of electric current and potential difference. There was no randomization of the research subjects. Secondly, ex-post facto design was also adopted. Basic Electricity practical skills existed in the students prior to the study and the researchers did not manipulate them. The population for the study was thirty seven Physics Education undergraduate students, from the Department of Science and Computer Education, Enugu State University of Science and Technology (ESUT), sourced from the official records during the 2016/2017 academic session. There was no sampling. The instruments used for data collection included battery eliminator, one Ohm standard resistor, one-way plug key, two multi-meters, some connecting wires and the undergraduates' science notebooks. The essay set of Physics practical instructions was developed by the researchers.

The two experts in Physics Education from the Department of Science and Computer Education, ESUT produced binary Q-matrix for the study. Areas of divergences in the Q-matrix specifications by the content experts were sorted out in the final Q-matrix. Table1 shows the Physics attributes and the number of items that measured each attribute. Table 2 shows the final Q-matrix for the basic electricity practical test. From Table 2, each of the thirty items measured at least four nested practical skills in basic electricity. The essay examination was administered to the respondents in four batches by the researchers. The data collected were analyzed with the final Q-matrix using GDINA package version 1.4.2 in r computer programme version 3.4.3 via R-studio version 1.0.153. The differential item functioning DIF based on gender,

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specifically Mantel Hanszel's method (difMH) in r 3.5.1 was conducted on the items of the test. The result indicated that all the items did not show significant DIF based on gender. Moreover, guessing and slipping parameter values that were less than .5 were flagged as good items (Zhang, 2015).

Table 1: Physics Attributes

Basic Electricity Practical Skills	Items
1. Connect battery eliminator E, 1 Ohm standard resistor, one-way plug key, K and digital multi-meter (functioning as Ammeter) in series	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19 and 20
2. Connect a digital multi-meter (functioning as voltmeter) in parallel to 1 Ohm standard resistor.	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19 and 20
3. Set E=1.5V, 3V, 4.5V, 6V and 7.5V once in each experimental time	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19 and 20
4. Tightly close one-way key K	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19 and 20
5. Record the Ammeter reading, I and Voltmeter reading, V	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19 and 20
6. Evaluate I^{-1} and V^{-1}	3,4,7,8,11,12,15,16,19 and 20
7. Repeat the procedure for four other values of E= 3V, 4.5V, 6V and 7.5V and in each case determine the corresponding I, V, I^{-1} and V^{-1}	5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19 and 20
8. Tabulate the readings	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15,16,17,18,19 and 20
9. From a zero origin, plot a graph of V^{-1} against I^{-1}	3,4,7,8,11,12,15,16,19,20 ,21,22,23,24,25,26,28 and 30
10. Determine the slope with vertical intercept of the best line graph through the plotted points	27 and 29
Total number of items	30

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Table2: Q-matrix for the basic electricity practical test

Items	Basic Electricity Practical skills									
	1	2	3	4	5	6	7	8	9	10
1.($Pd_{1.5V}$)	1	1	1	1	1	1	0	1	0	0
2.($I_{1.5V}$)	1	1	1	1	1	1	0	1	0	0
3.($Pd^{-1}_{1.5V}$)	1	1	1	1	1	1	0	1	1	1
4.($I^{-1}_{1.5V}$)	1	1	1	1	1	1	0	1	1	1
5.(Pd_{3V})	1	1	1	1	1	1	1	1	0	0
6.(I_{3V})	1	1	1	1	1	1	1	1	0	0
7.(Pd^{-1}_{3V})	1	1	1	1	1	1	1	1	1	1
8.(I^{-1}_{3V})	1	1	1	1	1	1	1	1	1	1
9.($Pd_{4.5V}$)	1	1	1	1	1	1	1	1	0	0
10.($I_{4.5V}$)	1	1	1	1	1	1	1	1	0	0
11.($Pd^{-1}_{4.5V}$)	1	1	1	1	1	1	1	1	1	1
12.($I^{-1}_{4.5V}$)	1	1	1	1	1	1	1	1	1	1
13.(Pd_{6V})	1	1	1	1	1	1	1	1	0	0
14.(I_{6V})	1	1	1	1	1	1	1	1	0	0
15.(Pd^{-1}_{6V})	1	1	1	1	1	1	1	1	1	1
16.(I^{-1}_{6V})	1	1	1	1	1	1	1	1	1	1
17.($Pd_{7.5V}$)	1	1	1	1	1	1	1	1	0	0
18.($I_{7.5V}$)	1	1	1	1	1	1	1	1	0	0
19.($Pd^{-1}_{7.5V}$)	1	1	1	1	1	1	1	1	1	1
20.($I^{-1}_{7.5V}$)	1	1	1	1	1	1	1	1	1	1
21.(UVS)	1	1	1	1	0	0	0	0	0	1
22.(UHS)	1	1	1	1	0	0	0	0	0	1
23.(VSU)	1	1	1	1	0	0	0	0	0	1
24.(HSU)	1	1	1	1	1	0	0	0	0	1
25.(CPP)	1	1	1	1	0	1	1	0	0	1
26.(BLF)	1	1	1	1	0	1	1	0	0	1
27.(VI)	1	1	1	1	0	1	1	0	0	1
28.(LT)	1	1	1	1	0	0	1	0	0	0
29.(SLOPE)	1	1	1	1	0	1	1	0	0	1
30.(SU)	1	1	1	1	0	0	0	0	0	0

KEY: **$Pd_{1.5V}$**=Potential difference in the circuit when the supply voltage was set to 1.5V. **$I_{1.5V}$**=Current in the circuit when the supply voltage was set to 1.5V. **$Pd^{-1}_{1.5V}$**=Inverse of the potential difference in the circuit when the supply voltage was set to 1.5V. **$I^{-1}_{1.5V}$**= Inverse of current in the circuit when the supply voltage was set to 1.5V. **UVS**= Uniform vertical scale. **UHS**= Uniform horizontal scale. **VSU**= Vertical scale's unit. **HSU**=Horizontal scale's unit. **CPP**=Correct plotting of points. **BLF**= Best line of fit. **VI**= Vertical intercept. **LT**= Large triangle. **SLOPE**= Slope. **SU**= Slope's unit.

RESULTS

The results were presented according to the research questions that were formulated to guide the study.

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Research question 1 (RQ1): What is the probability of correct response of the basic electricity items?

The data presented in Table 3 were used to answer RQ1.

Table3: The probability of correct response of the basic electricity items.

Item	Probability of correct response	Item	Probability of correct response
1	0.5172414	**16**	0.6551724
2	0.5800069	**17**	0.5517241
3	0.7862066	**18**	0.4827586
4	0.5173414	**19**	0.5506897
5	0.4827586	**20**	0.3179414
6	0.6517241	**21**	0.4482759
7	0.5862069	**22**	0.5172414
8	0.5777241	**23**	0.8860069
9	0.5517001	**24**	0.8620169
10	0.7862009	**25**	0.6172410
11	0.6206897	**26**	0.4977586
12	0.4406897	**27**	0.5787241
13	0.4827586	**28**	0.5862069
14	0.4482759	**29**	0.8717241
15	0.6517241	**30**	0.4717241

Item 20 had 32% as probability of correct response. Items: 1, 2, 4, 7, 8, 9, 17, 19, 22, 27 and 28 had probability values of mastery ranging from 52% to 59%. Also, items 6, 11, 15, 16 and 25 had values ranging from 62% to 66%. Two items: 3 and 10 each had value of 79%. Items 23, 24 and 29 had values which ranged between 86% to 89%.

Research question 2 (RQ2): What is the probability of guessing the basic electricity skills?

The data presented in Table 4 were used to answer RQ2.

Table 4: Skill Guessing

Skill	Intercept
1	0.0726
2	0.0358
3	-0.1322
4	0.1260
5	0.2454
6	0.2005
7	0.7210
8	-0.0748
9	0.1307
10	0.5521

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From Table 4, skills 3 and 8 had intercept (representing skill guessing) values of -0.1322 and -0.0748 respectively. Skills 2, 1, 4, 9, 6, 5, 10 and 7 had positive intercept values of .0358, .0728, .1260, .1307, .2005, .2454, .5521 and .7210 respectively in increasing order of magnitude.

Research question 3 (RQ3): What are the slipping with guessing parameters of the practical test items?

The data presented in Table 5 were used to answer RQ3.

Table 5: The slipping with guessing parameters of the practical test items

Item	Guessing	Slipping	Item	Guessing	Slipping
Item1	0.0034	0.0222	**Item16**	0.0796	0.1345
Item2	0.0006	0.0002	**Item17**	0.3795	0.1505
Item3	0.2065	0.4038	**Item18**	0.2606	0.2321
Item4	0.0161	0.0161	**Item19**	0.0726	0.0170
Item5	0.3357	0.4193	**Item20**	0.2274	0.1091
Item6	0.0075	0.0026	**Item21**	0.0528	0.0461
Item7	0.0035	0.0013	**Item22**	0.0020	0.0064
Item8	0.0064	0.0028	**Item23**	0.0005	0.0004
Item9	0.0060	0.0020	**Item24**	0.1408	0.0924
Item10	0.0755	0.2346	**Item25**	0.0313	0.0313
Item11	0.1252	0.2099	**Item26**	0.1759	0.1759
Item12	0.2706	0.1445	**Item27**	0.0027	0.0015
Item13	0.1805	0.1855	**Item28**	0.0045	0.0016
Item14	0.2744	0.0334	**Item29**	0.0173	0.0040
Item15	0.2643	0.1851	**Item30**	0.0142	0.0044

From Table 5 the guessing and slipping parameters ranged from .0005 to .3357 and .0002 to .4193 respectively.

DISCUSSION OF FINDINGS

The undergraduate students exhibited varying levels of correctly responding to the items of basic electricity practical test. Correct determination of the unit on the vertical scale, drawing the best line of fit and determination of the correct unit of slope were problematic to the undergraduates. Correct determination of the inverse of current, with respect to 7.5 voltage source had the least mastery by the undergraduates in the practical test. The reason for that could be adduced to carelessness on the part of the undergraduates. The mastery levels for determination of electric current and potential difference when the circuit voltage was set to 1.5 voltage, determination of the inverse of current when the circuit voltage was 1.5 volts were less than or equal to 59%. In addition, other items which had similar range of mastery included the determination of the inverse of current and potential difference when the supply voltage was set to 3 volts. Also in the range were the determinations of the potential difference when the supply voltage was set to 4.5 volts and 7.5 volts respectively. Potential difference inverse when the supply voltage was 7.5 volts. The determination of correct uniform horizontal scale, vertical intercept and large triangle from the best line of fit had their mastery level being less than or equal to 59% by the undergraduates.

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However, ten items had their mastery levels ranging from 62% to 89% in the test. They included the determination of inverse of current and potential difference when the supply voltage was 1.5volts, 3volts, 4.5volts, 6 volts and correct plotting of points. Others were correct determination of current when the supply voltage was set to 3 volts, determination of the standard unit on the vertical with horizontal scales and determination of slope of the line graph. The result of this study showed that the undergraduates exhibited fair knowledge about current and voltage measurement and the correct determination of their inverses. The observed result was in consonance with earlier report by WAEC resume of the Chief Examiners' report (n.d) that Physics students failed to record the inverse of current and voltage to at least three decimal places. Therefore, lower decimal points could have accounted for students' poor determination of inverse of current and voltages in an electric circuit. In addition, the inability of Physics students to correctly determine the inverse of current and voltages in external examinations could be traced to poor quality of teacher training. The implication of the result is that the lecturers in Physics Education and core Physics courses should devote more of their instructional time to practical in lieu of theory.

The result of second research question showed that electricity skills involving repeating the procedure for E=3V, 4.5V, 6V and 7.5V and determination of the slope with the vertical intercept had high guessing. The implication of the high guessing parameters of the electricity skills was that the mastery levels of the skills among the undergraduates were lower than other skills. More so, the rest of the skills had relatively lower guessing parameter. The two skills with higher guessing parameters should be taught to the students again to ensure their proper internalizations.

The result of research question three indicated that all the thirty items had normal guessing and slipping parameters. The result suggested that the test items were capable to measure the undergraduates' proficiency in basic electricity.

CONCLUSION

The result of the study showed that the undergraduates had difficulties in evaluating inverse of current and voltages to at least three decimal places. Manipulating the Electromotive force and the determination of the slope of a line graph was problematic to majority of the undergraduates. It was recommended that Physics Education lecturers should spend more of their instructional time to practical in lieu of theory.

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APPENDIX A: R CODES FOR THIS STUDY'S GDINA MODEL EVALUATION.

```
library("GDINA") #run

setwd("C:/Users/NNADI/Desktop/DINA")

example44<-read.table("example44.txt")

qmatrix44<-read.table("qmatrix44.txt")

colnames(example44)=c("item1","item2","item3","item4","item5","item6",
                 "item7","item8","item9","item10","item11","item12",
                 "item13","item14","item15","item16","item17","item18",
                 "item19","item20","item21","item22","item23","item24",
                 "item25","item26","item27","item28","item29","item30")#run

colnames(qmatrix44)=c("attribute1","attribute2","attribute3",
                 "attribute4","attribute5","attribute6",
                 "attribute7","attribute8","attribute9",
                 "attribute10")#run

V<-GDINA(example44, qmatrix44, model = "GDINA", att.dist="higher.order",
       higher.order=list(method="MMLE"),
       verbose = 1)

itemparm(V, what = "gs") # guessing and slipping parameters

hoest=hoparm(V) # extract higher-order parameters

hoest$lambda # structural parameters

itemparm(V, withSE = TRUE) # item probabilities of success & standard errors

itemparm(V, what = "gs",withSE = TRUE) # guessing and slipping parameters & standard
errors

itemparm(V) # item probabilities of success for each latent group
```


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