Using the Attribute Hierarchy Method to Make Diagnostic Inferences about Examinees' Cognitive Skills

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OVERVIEW

- The purpose of my presentation is to describe our program of research—funded by the College Board—on a new cognitive diagnostic testing procedure called on the attribute hierarchy method (AHM)
- The AHM is a psychometric method for classifying examinees' test item responses into a set of structured attribute patterns associated with different components from a *cognitive model of task performance*
- This method helps link cognitive theory and psychometric practice to facilitate the development and analyses of educational and psychological tests—results from AHM analyses yield information on examinees' problem-solving strengths and weaknesses

OUTLINE FOR PRESENTATION

- In the **first section** of the presentation we define the phrase *cognitive model* in educational measurement and we explain why these models are important in the development and analysis of diagnostic assessments

- In the **second section** we illustrate how the AHM can be used to make diagnostic inferences using data from algebra items on the March 2005 administration of the SAT; we will also explain how this diagnostic information can be reported to students, parents, and teachers

THE BIG PICTURE

- Educational and psychological measurement is undergoing profound changes, as developments in **computing science**, **educational technology**, **statistical modeling**, and **cognitive psychology** are beginning to permeate the assessment field

- These developments not only have a direct effect on the theories and practices in test, but they also bring to bear a inter-disciplinary focus

- The influence of cognitive psychology on educational measurement, which began as a trickle almost 20 years ago (cf. Snow & Lohman, 1989), has become a torrent of activity contributing to the ideas and innovations in skills diagnostic testing [e.g., Leighton, J. P. & Gierl, M. J. (in press). *Cognitive Diagnostic Assessment: Theory and Practices.* Cambridge University Press.]

THE BIG PICTURE

- Assessment engineering (AE; Luecht, 2006a, 2006b) is an innovative approach to measurement where engineering-like principles are used to direct the design and analysis of assessments as well as the scoring and reporting of the results
- AE requires three explicit steps:

STEP #1: An assessment begins with specific, empirically-derived cognitive models of task performance;

STEP #2: Assessment task templates are created from cognitive models to produce replicable test items;

STEP #3: Psychometric methods are applied to the examinee response data, typically in a confirmatory mode, to produce scores that are both replicable and interpretable

SECTION 1: COGNITIVE MODELS

- A cognitive model refers to a simplified description of human problem solving on standardized tasks at some convenient level of detail in order to facilitate explanation and prediction of students' performance, including their strengths and weaknesses (Leighton & Gierl, in press)

- These models provide an interpretative framework that can guide item development so test performance can be linked to specific cognitive inferences about examinees' skills

- BENEFIT: Strong inferences about examinees' cognitive skills can be made because the small grain size in these models help illuminate the knowledge and skills required to perform competently on testing tasks

SECTION 2: ATTRIBUTE HIEARCHY METHOD (AHM)

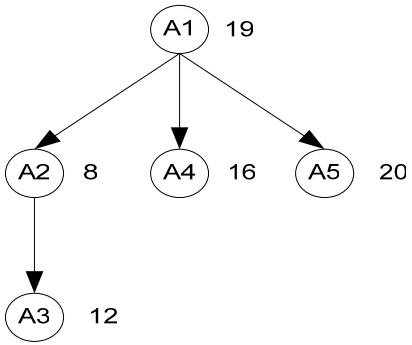
- The AHM is a psychometric method for classifying examinees' test item responses into a set of structured attribute patterns associated with different components from a *cognitive model of task performance*

- An attribute is a description of the procedural or declarative knowledge needed to perform a task in a specific domain—these attributes form a *hierarchy* that define the psychological ordering among the attributes required to solve a test item

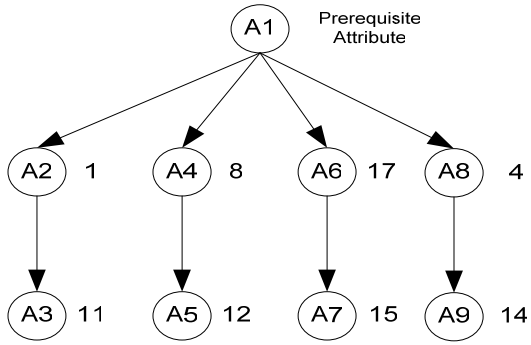
- The attribute hierarchy serves as a cognitive model of task performance, which guides item development so test performance can be linked to specific cognitive inferences about each examinee

SECTION 2: ATTRIBUTE HIEARCHY METHOD (AHM)

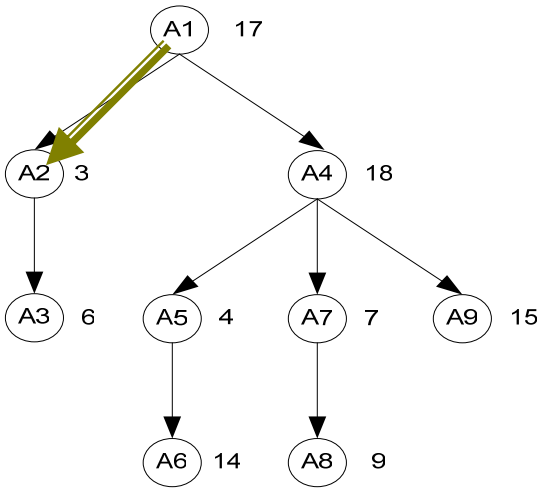
STAGE 1: DEFINE COGNITIVE MODEL



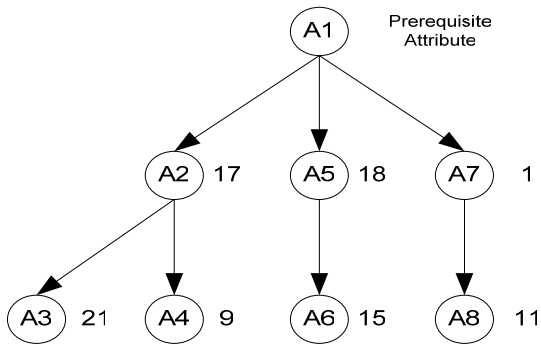
Hierarchy 1: Exponents and Algebra



Hierarchy 2: Basic Algebra



Hierarchy 3: Ratios and Algebra



Hierarchy 4: Equation and Inequality Solution, Algebraic Operation, Algebraic Substitution, and Exponents

LINK

SECTION 2: ATTRIBUTE HIEARCHY METHOD (AHM)

STAGE 2: EVALUATE PSYCHOMETRIC PROPERTIES

- In stage 2, the psychometric properties of the cognitive model are evaluated

- Attribute probabilities can be computed for each examinee thereby providing specific information about their attribute-level performance

- We have also developed procedures for evaluating model-data fit using the Hierarchy Consistency Index so the degree to which an observed examinee response pattern is consistent with the attribute hierarchy can be discerned; for measuring attribute reliability, which refers to the consistency of the decisions made in a diagnostic test about examinees' mastery of specific attribute; and for assessing differential attribute functioning which allows us to study subgroup differences at the attribute level

SECTION 2: ATTRIBUTE HIEARCHY METHOD (AHM)

- Attribute probabilities provide examinees with specific information about their attribute-level performance—to estimate these probabilities, a neural network is used

- The relationship between the expected response vectors with their associated attribute vectors is established by presenting each pattern to the network repeatedly until it “learns” each association

- Then, each examinee observed response pattern is mapped onto the expected response vector to evaluate attribute mastery

SECTION 2: ATTRIBUTE HIEARCHY METHOD (AHM)

- Using data from a random sample of 5000 students who wrote the March administration of the SAT, the probabilities associated with each attribute for all examinees was computed
- The following sample results from three observed patterns highlight the nature of the reported outcomes:

Pattern	*Attribute Probability*								
	1	2	3	4	5	6	7	8	9
1. A1 to A3	0.96	0.99	0.93	0.04	0.00	0.00	0.00	0.00	0.00
2. A1, A4 to A6	0.99	0.01	0.02	0.98	0.96	0.98	0.02	0.00	0.02
3. A1, A4 to A8	0.97	0.02	0.00	0.99	0.96	0.99	0.96	0.99	0.02

LINK

THE BIG PICTURE—REVISITED

- Assessment engineering (AE; Luecht, 2006a, 2006b) is an innovative approach to measurement where engineering-like principles are used to direct the design and analysis of assessments as well as the scoring and reporting of the results
- AE requires three explicit steps:

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SECTION 3: CONCLUSIONS

- The AHM, which is an *AE method*, also uses these three steps:

STEP #1: The cognitive model of task performance is specified—this model defined the construct measured by the test and is operationalized by describing the attributes and then ordering these attributes in a hierarchy;

STEP #2: The cognitive model guides the creation of the task templates required for item construction so items that measure each specific attribute combination defined in the hierarchy can be created;

STEP #3: The examinee response data are analyzed using a confirmatory analytic approach, with the neural network, where the examinee's cognitive strengths and weaknesses can be evaluate on each attribute measured by the test

THANK YOU

If you have questions or comments, please contact me

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REFERENCES

ATTRIBUTE HIERARCHY METHOD:

1. Leighton, J. P., Gierl, M. J., & Hunka, S. (2004). The attribute hierarchy method for cognitive assessment: A variation on Tatsuoka's rule-space approach. *Journal of Educational Measurement, 41,* 205-237.

2. Gierl, M. J., Cui, Y., & Hunka, S. (2007). The attribute hierarchy method for cognitive assessment: Technical developments. *Applied Measurement in Education.* Manuscript submitted for publication.

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COGNITIVE DIAGNOSTIC ASSESSMENT:

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2. Leighton, J. P., & Gierl, M. J. (in press). Identifying and evaluating cognitive models in educational measurement. *Educational Measurement: Issues and Practice.*