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ABSTRACT

The 1999 Advanced Placement[R] (AP[R] Psychology Examination contains items drawn from 13 factors related to the study of psychology. This factor structure had not been explored previously. This study focuses on evaluating the fit of confirmatory factor analysis (CFA) models to examination items. Since examination items were dichotomous and polytomous, the CFA models were fit to polychoric correlation matrices using weighted least squares with the inverted matrix of asymptotic variance/covariance estimates serving as the weight matrix (W-1). A rationale for using this method is provided. The correlations among items, as well as their asymptotic variances and covariances, were estimated with PRELIS 2.3, and the CFA was performed with LISREL 8.3 (K. Joreskog and D. Sorbom, 1999). Results indicate that the proposed CFA models fit the data well, which suggests that the theoretical factor structure of the examination is plausible. The paper discusses limitations and next steps. (Contains 1 table, 13 figures, and 25 references.) (Author/SLD)

Running head: MEASURING INTRODUCTORY PSYCHOLOGICAL CONSTRUCTS

Measuring Knowledge of Introductory Psychology: What are the Relevant Constructs?

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Paper presented at the annual meeting of the American Psychological Association

in San Francisco, California, August 2001

Abstract

The 1999-Advanced Placement® (AP®) Psychology Exam contains items drawn from 13 factors related to the study of psychology. Heretofore, this factor structure had not been explored empirically. Therefore, the current study focuses on evaluating the fit of confirmatory factor analysis (CFA) models to exam items. Since exam items were dichotomous and polytomous, the CFA models were fit to polychoric correlation matrices using weighted least squares with the inverted matrix of asymptotic variance/ covariances estimates serving as the weight matrix (W^{-1}). A rationale for using this method is provided. The correlations among items, as well as their asymptotic variances and covariances, were estimated with PRELIS 2.3 and the CFA was performed with LISREL 8.3 (Jöreskog & Sörbom, 1999). Results indicated that the proposed CFA models fit the data well, which suggests that the theoretical factor structure of the exam is plausible. Limitations and next steps are discussed.

Measuring Knowledge of Introductory Psychology: What are the Relevant Constructs?

The College Board's Advanced Placement Program® (AP®) offers a course and examination to qualified students who wish to complete studies in secondary school that are equivalent to an introductory college course in psychology (The College Board, 1999a). The principals of the AP Psychology course, as indicated by The College Board (1999a), are repeated here:

> The purpose of the AP course in psychology is to introduce students to the systematic and scientific study of the behavior and mental processes of human beings and other animals. Students are exposed to the psychological facts, principals, and phenomena associated with each of the sub-fields within psychology. They also learn about the methods that psychologists use in their science and practice (p. 3).

These principals create an excellent learning environment for AP Psychology students. A cumulative exam at the end of the school year measures proficiency in knowledge acquired from course work.

The 1999 AP Psychology examination is representative of the content covered in a college level introductory course in psychology; it is therefore considered appropriate for measuring skills and knowledge in introductory psychology. (The College Board, 1999a). Grades on the AP Psychology exam are intended to allow participating colleges and universities to award college credit, advanced placement, or both to qualified students (The College Board, 1999b).

The AP Psychology exam is theorized to measure 13 content domains, or factors, related to the study of psychology. The following is a list of labels for the content domains covered by the exam: a) Method, Approaches, History; b) Biological Bases of Behavior, c) Sensation and

Perception; d) States of Consciousness; e) Learning; f) Cognition; g) Motivation and Emotion; h) Developmental Psychology; i) Personality; j) Testing and Individual Differences; k) Abnormal Psychology; l) Treatment of Psychological Disorders; m) Social Psychology.

The AP Psychology Examination consists of a 70-minute multiple-choice and a 50-minute free response section. The multiple-choice questions comprise two-thirds of a student's grade. There are two free response questions that evaluate "a student's mastery of scientific research principles and ability to make connections among constructs from different psychological domains" (The College Board, 1999a).

The development of the AP examinations involves an extensive process taking several years. Committees comprised of secondary school teachers and college professors in cooperation with test development experts at ETS have authority over developing the AP tests. Committee members bring to their knowledge of the curricula and instructional methods in their fields. As faculty members, they know the abilities and skills that are critical to mastery in a given subject, and how students can demonstrate them. Faculty consultants score free-response questions. Detailed scoring guidelines and various "checks and balances" ensures inter-rater reliability of scoring (The College Board, 1999a)

Despite careful development of test items and a clear description of their associated content domains, it has not been determined empirically whether The College Board's 1999 AP Psychology test measures what it intends to measure. The purpose of the current study is to explore the construct validity of the exam through an application of confirmatory factor analysis (CFA). Our rationale for undertaking this kind of investigation is based almost directly on Messick (1989):

> Construct validity is evaluated by investigating what qualities a test measures, that is, by determining the degree to which certain explanatory concepts or constructs account for performance on the test (p. 16)

Factor analysis can be considered one method of investigating the construct validity of a test. However, since both dichotomous and polytomous variables comprise the test data, traditional factor analytic methods are insufficient for addressing this purpose.

Problems with factor analyzing dichotomous data were originally identified within the field of exploratory factor analysis. The major problem is that spurious item *difficulty* factors tend to be extracted when traditional methods are applied to dichotomous data. Such spurious factors were first noticed in the realm of intelligence tests in instances where factor analytic solutions yielded several factors with items of similar difficulty grouped together (Gorsuch, 1983). The restriction in the range of data for dichotomous test items reduces the phi correlations among these variables, which results in spurious factors being extracted during factor analysis. Similar problems arise when CFA is performed on dichotomous data except that instead of spurious factors being extracted, plausible models are rejected in favor of other models that are less parsimonious.

Several researchers have proposed alternative methods for factor analyzing dichotomous data. One approach is to create *parcels* of dichotomous items and then factor analyze the correlations or covariances among these parcels (Dorans & Lawrence, 1999). By collapsing items into parcels and making them roughly continuous, this procedure corrects for the restriction in range in the dichotomous items. To implement this procedure correctly, parcels should contain a sufficient number of easy, middle-difficulty, and hard items (Dorans & Lawrence, 1999). Researchers should be aware that the parcel approach does not address dimensionality at the item level because an item may measure a property that is lost in the analysis of parcels (Dorans & Lawrence, 1987). Therefore, the parcel approach may not be appropriate if one is interested in exploring the item-level structure of the test through factor analysis.

A second alternative for factor analyzing dichotomous variables was developed by Bock and Aitken (1981) and is generally referred to as full-information factor analysis. It is so named because the approach makes uses of the dichotomous responses to the items as well as their item response theory (IRT) parameters. Essentially, this procedure is based on Thurstone's (1947) multiple-factor model where an unobservable response pattern, Y_{ij}, for person i and item j, is a linear combination of *m* normally distributed latent variables, θ, weighted by the factor loadings, α

(1) $$Y_{ij} = \alpha_{j1}\theta_{1i} + \alpha_{j2}\theta_{2i} +,\ldots,+ \alpha_{jm}\theta_{mi} + \delta_i;$$

the parameters in the model (1) are estimated by marginal maximum likelihood and the EM algorithm (Muraki & Englehard, 1985). A routine for performing full-information factor analysis is available in TESTFACT 2 (Wilson, Wood & Gibbons, 1991) however, the current software places an upper bound limit on the number of factors that can be extracted and is not equipped to analyze both dichotomous and polytomous item responses simultaneously.

McDonald (1967) proposed non-linear factor analysis, another alternative technique for factor analyses of dichotomous data that also expands on Thurstone's (1947) multiple factor analysis model. McDonald's factor analytic model assumes that there is a non-linear relationship between the items and the factors. Including polynomials in a modified form of Thurstone's (1947) multiple factor analysis model captures the non-linear relationship between the items and factors. Non-linear factor analysis can be expressed mathematically by the following form

(2) $$y_i = a_{iO} + \sum_{f=1}^{f}\sum_{p=1}^{s} a_{ilp}\theta_l^p \qquad (i = 1,2, \ldots, n)$$

where y_i is an examinee's score on item i,

f is the number of factors necessary to account for examinee test performance,

s is the degree of the polynomial used to fit the model with each factor, and,

a_{ilp} is the factor loading of the ith item on the lth factor for the pth degree element in the polynomial (Hambleton & Rovinelli, 1986). Essentially, non-linear factor analysis involves fitting a series of increasingly complex models, where models differ in complexity by the order of the polynomial used. Factor loadings are estimated from the model with the polynomial that best fits the data. Non-linear factor analysis is a well reasoned approach to assessing the dimensionality of a set of dichotomous test items however, the current software NOHARM (Normal Ogive Harmonic Analysis Robust Method) program (Fraser, 1988) is limited in situations where data are comprised of both dichotomous and polytomous responses.

Still yet another alternative for factor analyzing dichotomous data involves using weighted least squares in LISREL 8.3 (Jöreskog & Sörbom, 1999), a procedure that is based on the asymptotically distribution free method developed by Browne (1984). The first step to implementing this procedure involves using PRELIS 2.3 (Jöreskog & Sörbom, 1999) to compute estimates of the asymptotic variance and covariances of estimated tetrachoric, polychoric or polyserial correlations among model indicators (Jöreskog & Sörbom, 1996). The inverted asymptotes are used as a weight matrix, W^{-1}, during minimization of the fit function

(3) $$F(\theta) = (s-\sigma)' W^{-1} (s-\sigma)$$

where $s' = (s_{11}, s_{21}, s_{22}, s_{31}, \ldots, s_{kk})$ (Jöreskog & Sörbom, 1996). LISREL minimizes the fit function (3) to estimate model parameters and fit indices. Preliminary research (Hu, Bentler, &

Kano, 1992) shows that the asymptotically distribution free method offers highly accurate estimates of χ^2, and other χ^2 dependent tests (e.g. RMSEA, NCP, etc.) under conditions where sample sizes are large (> 5,000).

For several reasons, weighted least squares was the confirmatory factor analytic method implemented in the current study. First, practical and substantive issues limited the feasibility of employing the parcel approach. Since, on average, eight items were associated with the factors in the current model, parcels with "approximately equal means and variances" as well as equal representations of "easy, middle, and hard items" could not be reasonably constructed (Dorans & Lawrence, 1999). Moreover, due to the fact that the current study is concerned with the item-level structure of the exam, and not the macro, parcel-level structure, this approach was not appropriate. Second, computer programs for full-information factor analysis and non-linear factor analysis, TESTFACT 2 (Wilson, Wood, & Gibbons, 1991) and NOHARM (Fraser, 1988) respectively, are not equipped to deal with dichotomous and polytomous items simultaneously. In addition, the upper bound limit on the number of factors that can be extracted using TESTFACT 2 prevents testing the current model. Third, under conditions where there is a large sample, the weighted least squares procedure offers a sufficient solution to the methodological problems associated with factor analyzing tests comprised of dichotomous and polytomous items.

It was not possible to fit a CFA model that took into account the 100 exam indicators and 13 latent factors using weighted least squares. An extreme computational burden is associated with the weighted least squares procedure as the number of items increases because the method requires generating and inverting the asymptotic variance/ covariance matrix of the estimated tetrachoric correlations (Bock, Gibbons & Muraki, 1988). Because the asymptotic variance/

covariance matrix is of the order $u * u$ (where u is the number of unique elements in the sample correlation or variance/ covariance matrix), and has $u(u + 1)/2$ distinct elements (Jöreskog & Sörbom, 1996), its size increases to an unwieldy degree as the number of items increases. For example, a model with 100 indicators would have a weight matrix of 12,753,775 distinct elements! As a result 13 separate models, one for each latent factor were fit to the data.

Method

Participants

A total of 28,013 AP psychology examinees comprised the current data set. The examinees were 9,364 (33.4%) male and 18,648 (66.6%) female students enrolled in AP psychology classes at secondary schools in the continental United States of America or an associated territory. All of the examinees received a score on the exam. Of the examinees, 70.6% were 12th graders, 27.2% were 11th graders and 2.1% were 10th graders. The ethnic composition of the participants was 0.5% American Indian or Alaskan Native, 1.8% African American or Black, 4.7% Asian, Asian American or Pacific Islander, 17.1% Hispanic or Latino, 67.4% White and 3.5% other; 6.1% of the examinees did not provide an ethnic description.

Materials

The AP exam in psychology contains a 70-minute section with 100 multiple choice questions and a 50-minute free-response section containing two essay questions. Item analysis revealed that two items were not functioning properly and were dropped from the test. The multiple choice and free response sections are designed to complement each other and to meet the overall course objectives and exam specifications (The College Board, 1999b). Multiple choice and free-response items are considered to be highly reliable.

Procedure

A series of one factor CFA models were fit to the data using LISREL 8.3 (Jöreskog & Sörbom, 1999). As mentioned, since both dichotomous and polytomous responses were observed, fitting these models to either the phi correlations or covariances would have biased the results obtained. Therefore, the models were fit to tetrachoric and polychoric correlations among items as well as their asymptotic variances and covariances using a weighted least squares procedure (Jöreskog & Sörbom, 1996). These correlations and asymptotes were estimated using PRELIS 2.3 (Jöreskog & Sörbom, 1999).

Based on several recommendations (Hu & Bentler, 1999; MacCallum & Austin, 2000) and standards within the field, a model was considered to provide an acceptable fit to the data if the root mean square error of approximation (RMSEA) was less than (0.05), the right endpoint of the 90% confidence interval for RMSEA was lower than (0.08), the standardized root mean square residual (SRMSR) was low (e.g. less than 0.10) and non-normed fit index (NNFI) was sufficiently close to (1.0) (e.g. > 0.90). It was not appropriate to use chi square χ^2 values as an index of model fit since analyses were performed on the entire population of test takers and not a random sample.

Because the current confirmatory factor analysis involved a strictly confirmatory situation in which a single formulated model is either accepted or rejected, it was not necessary to evaluate the plausibility of other competing models (Jöreskog & Sörbom, 1993).

Results and Discussion

Values on fit indices for every model demonstrated acceptable fit unambiguously (see Table 1). Therefore, CFA models can be considered tenable representations of the underlying structure of the unidimensional factors of which the test is comprised. Model parameter estimates of factor loadings were high in each model (see Figures 1-13). Most factor loadings were above (0.4) and only two out of the 110 path coefficients estimated were less than (0.2). Error variances associated with model indicators tended to be high (see Figures 1-13). In fact, practically every model fit to the data tended to yield estimates of error variances for each item that were higher than factor loadings associated with those items. This tendency does not necessarily imply poor model fit. It is more likely that the larger error variances reflect the unreliability of indicators comprised of a single item. Nevertheless, this result is perplexing and requires further attention.

The current results are limited in several ways. First, since it was not possible to fit the entire 13-factor model to all of the exam indicators, we cannot comment on whether the entire 13 factor model is supported empirically. Instead, we may only conclude from fit indices that the items associated with each factor appear to be unidimensional. While the finding is important in itself, it does not elucidate the nature of the entire factor structure of the exam. Despite this limitation, we can deduce, from the high factor loadings associated with each model fit to the data, that the items are highly related to latent variables in the models, which supports the construct validity of the exam.

Several recommendations for future research are warranted in light of the results of the current investigation. First, a factor model that accounts for the entire test structure should be fit to the data. This first step requires either a new algorithm for the weighted least squares procedure that can perform well under situations where the number of indicators is large, or a new method altogether. These concerns were voiced by Muthén (1984) but have yet to be addressed adequately.

Second, while the current results support the construct validity of the 13 factors measured by the 1999 AP Psychology Examination, it remains unseen whether the test contains items that encompass all of the factors relevant to the study of introductory psychology. In that respect, it would be interesting to undertake an extensive review of material related to introductory psychology in order to explore whether there are any relevant content domains missing from the test. This review might be accomplished by surveying introductory psychology professors and AP psychology teachers about the about the content domains they feel are most relevant to introductory psychology or by exploring the topics covered in introductory psychology textbooks.

It would also be interesting to explore the cognitive dimensions measured by the items of the AP Psychology exam and provide diagnostic feedback to students on cognitive skills. Advanced quantitative methods like multidimensional item response theory models MIRT (see Embretson & Reise, 2000), regression trees (Sheehan, 1997) and the rule-space model (Tatsuoka & Tatsuoka, 1992) are available for addressing research questions of this kind. Implementation of these methods offers not only greater insight into the psychometric properties of the test and its construct validity, but can also be a means for providing information about cognitive skills and instructional feedback to examinees- a worthy end.

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Table 1

Goodness of Fit Statistics for Each 1-Factor Model Fit to the Data

Model	Model Label	No. items	RMSEA	90% Confidence Interval for RMSEA	Standardized RMR	NNFI
1.	Methods, history, & approaches	8	0.017	0.015; 0.019	0.023	0.99
2.	Biological bases of behavior	11	0.027	0.025; 0.028	0.034	0.99
3.	Sensation & perception	9	0.024	0.022; 0.026	0.031	0.98
4.	States of consciousness	4	0.007	0.000; 0.015	0.006	1.00
5.	Learning	8	0.019	0.017; 0.021	0.018	1.00
6.	Cognition	11	0.028	0.027; 0.030	0.038	0.98
7.	Motivation & emotion	9	0.013	0.011; 0.015	0.019	1.00
8.	Developmental psychology	9	0.030	0.028; 0.032	0.037	0.98
9.	Personality	8	0.020	0.017; 0.022	0.022	0.99
10.	Testing & individual differences	6	0.015	0.012; 0.018	0.016	1.00
11.	Abnormal psychology	8	0.017	0.014; 0.019	0.019	0.99
12.	Treatment of psychological disorders	6	0.032	0.028; 0.035	0.031	0.99
13.	Social psychology	9	0.021	0.019; 0.023	0.024	0.99

Note. RMSEA = root mean square error of approximation; Standardized RMR = Standardized root mean square residual; NNFI = non-normed fit index.

Figure Captions

Figure 1. Factor loadings and error variances for model 1: Methods, approaches, and history.

Figure 2. Factor loadings and error variances for model 2: Biological bases of behavior.

Figure 3. Factor loadings and error variances for model 3: Sensation and perception.

Figure 4. Factor loadings and error variances for model 4: States of consciousness.

Figure 5. Factor loadings and error variances for model 5: Learning.

Figure 6. Factor loadings and error variances for model 6: Cognition.

Figure 7. Factor loadings and error variances for model 7: Motivation and emotion.

Figure 8. Factor loadings and error variances for model 8: Developmental psychology.

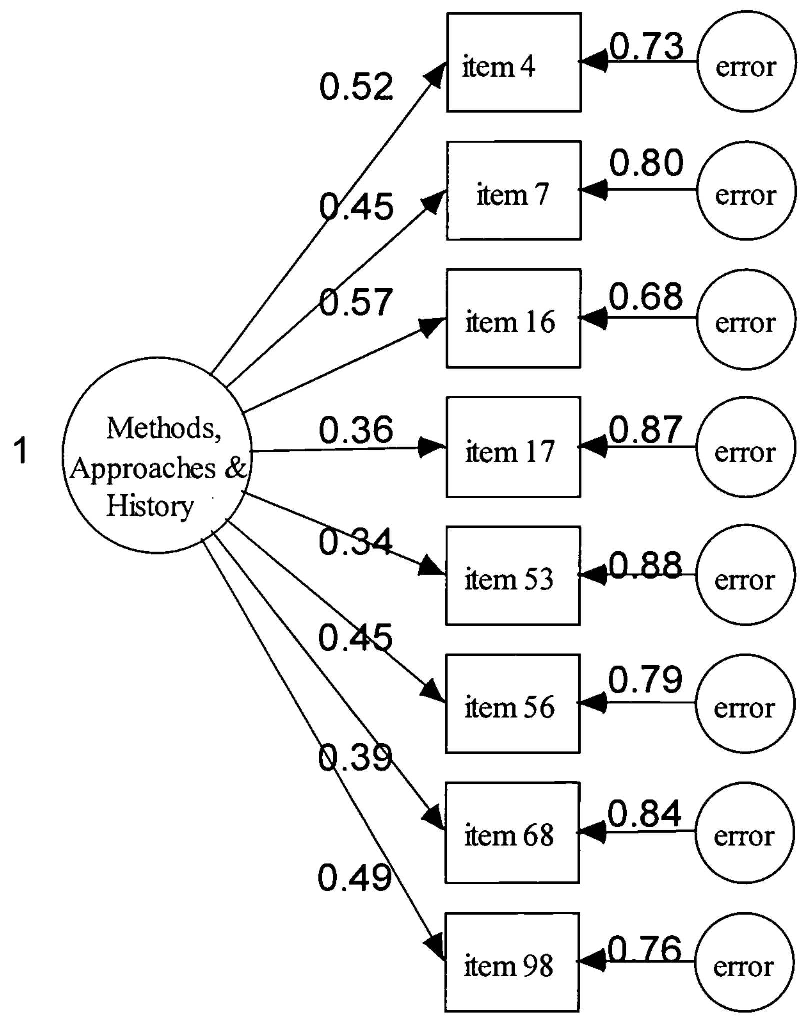
Figure 9. Factor loadings and error variances for model 9: Personality.

Figure 10. Factor loadings and error variances for model 10: Testing and individual differences.

Figure 11. Factor loadings and error variances for model 11: Abnormal psychology.

Figure 12. Factor loadings and error variances for model 12: Treatment of psycholgical disorders.

Figure 13. Factor loadings and error variances for model 13: Social psychology.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Methods, Approaches & History
0.52
0.45
0.57
0.36
0.34
0.45
0.39
0.49
item 4
item 7
item 16
item 17
item 53
item 56
item 68
item 98
0.73
0.80
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0.84
0.76
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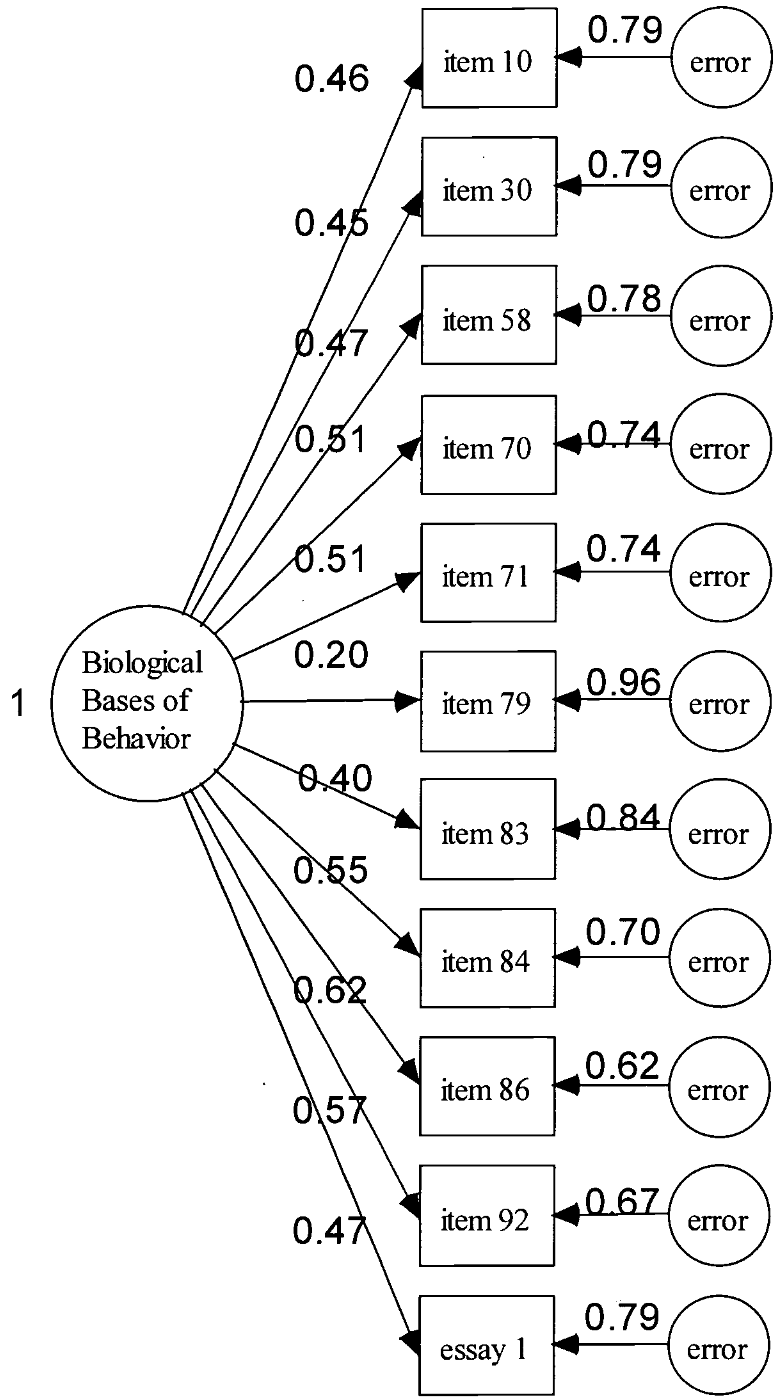
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Biological Bases of Behavior
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0.51
0.51
0.20
0.40
0.55
0.62
0.57
0.47
item 10
item 30
item 58
item 70
item 71
item 79
item 83
item 84
item 86
item 92
essay 1
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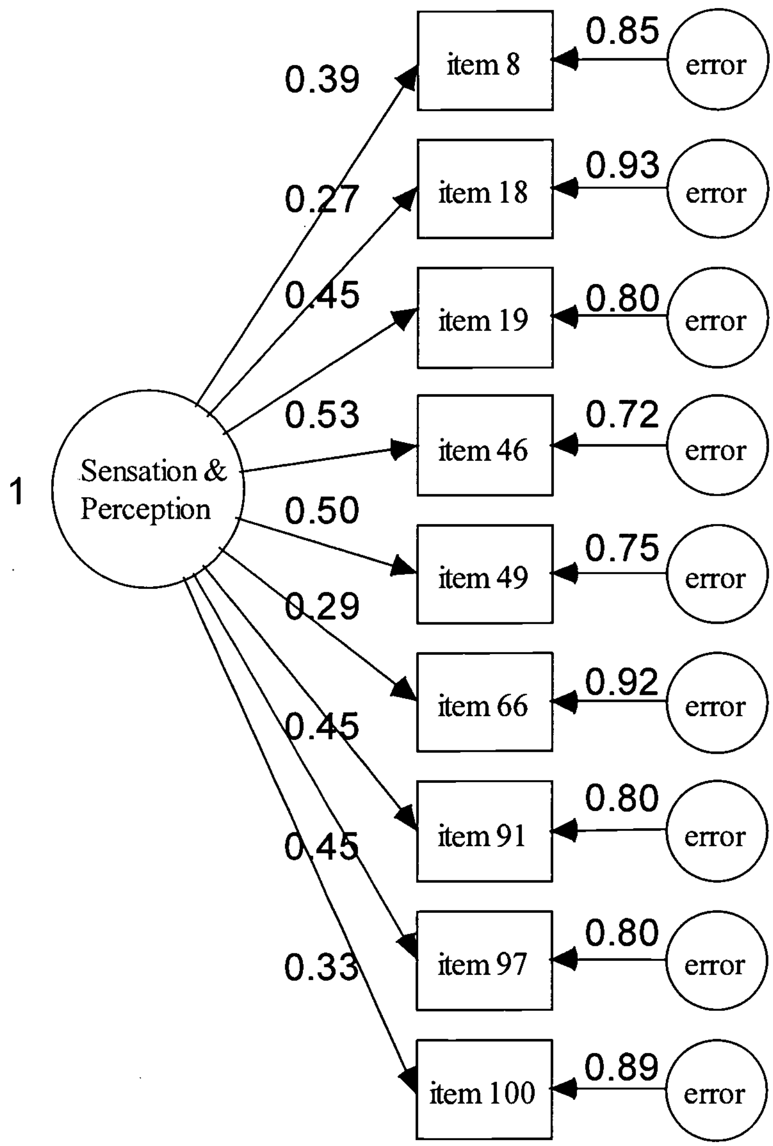
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Sensation & Perception
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0.45
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item 18
item 19
item 46
item 49
item 66
item 91
item 97
item 100
0.85
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0.80
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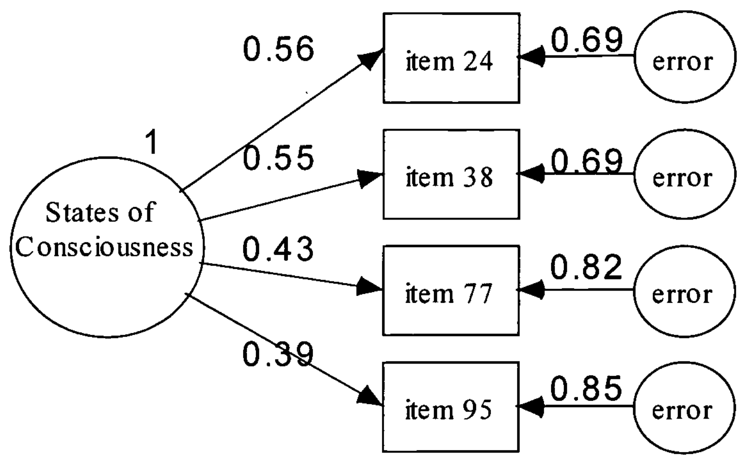
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item 38
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States of
Consciousness
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item 95
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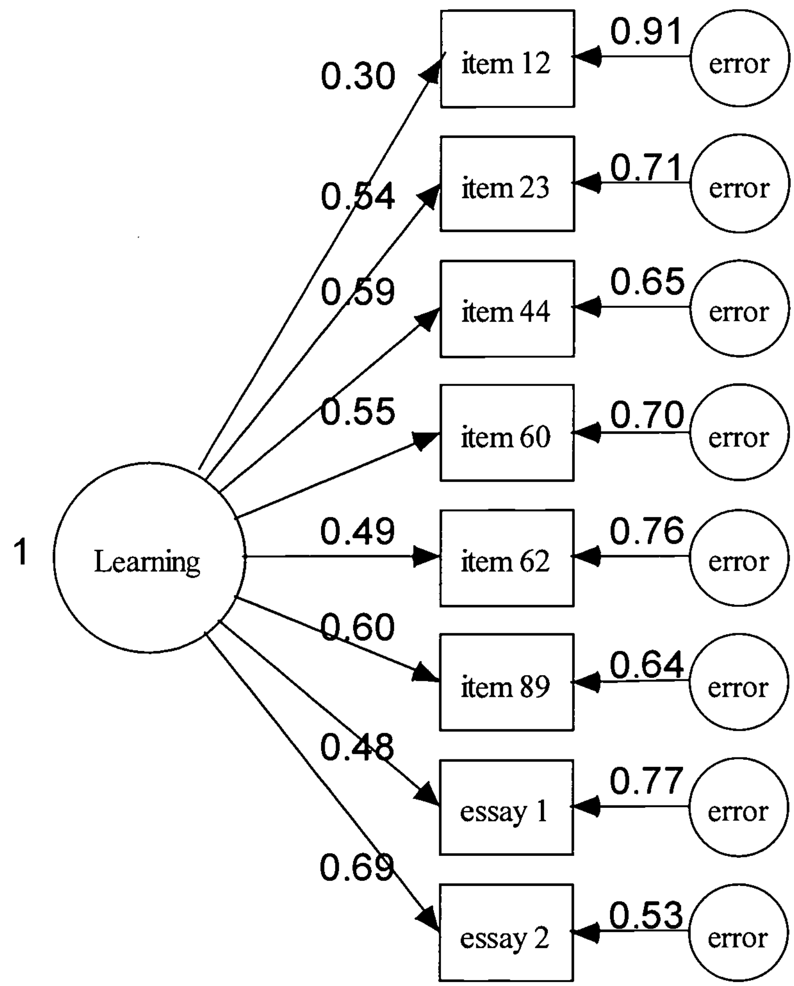
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Learning
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0.59
0.55
0.49
0.60
0.48
0.69
item 12
item 23
item 44
item 60
item 62
item 89
essay 1
essay 2
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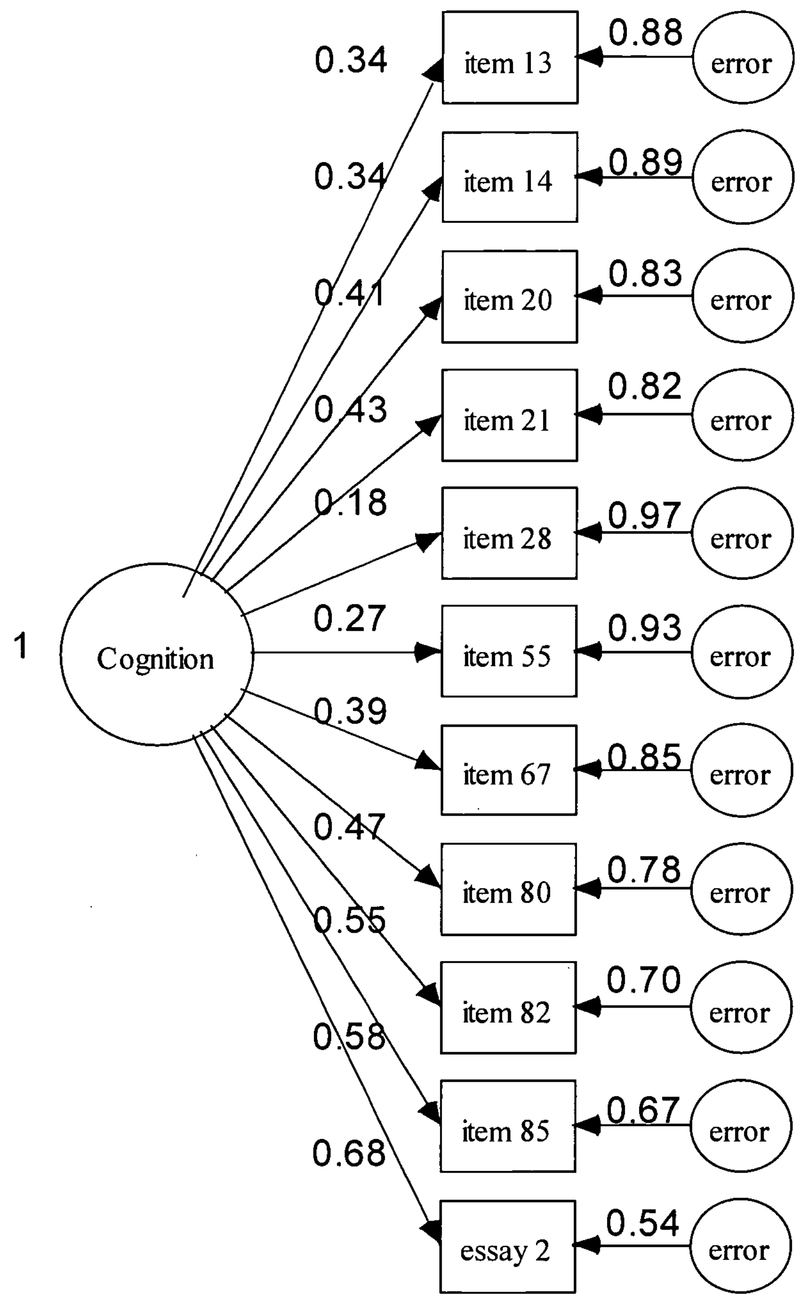
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0.55
0.58
0.68
item 13
item 14
item 20
item 21
item 28
item 55
item 67
item 80
item 82
item 85
essay 2
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0.89
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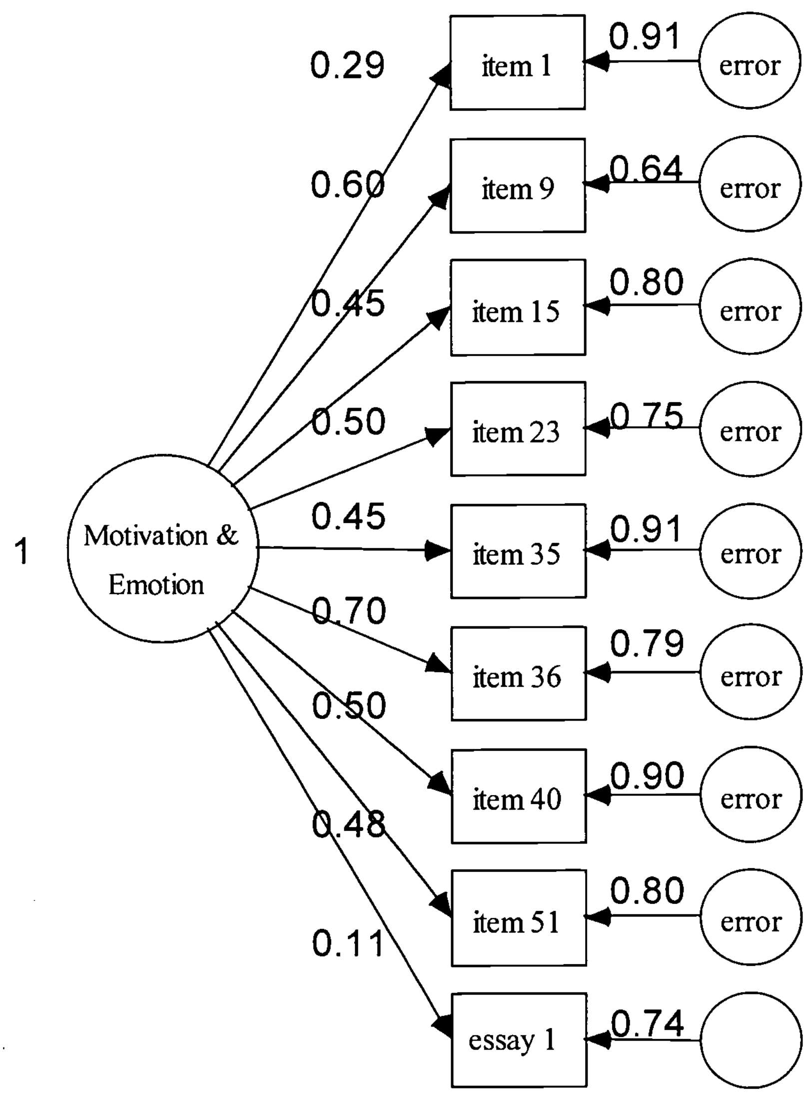
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Motivation & Emotion
0.29
0.60
0.45
0.50
0.45
0.70
0.50
0.48
0.11
item 1
item 9
item 15
item 23
item 35
item 36
item 40
item 51
essay 1
0.91
0.64
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0.90
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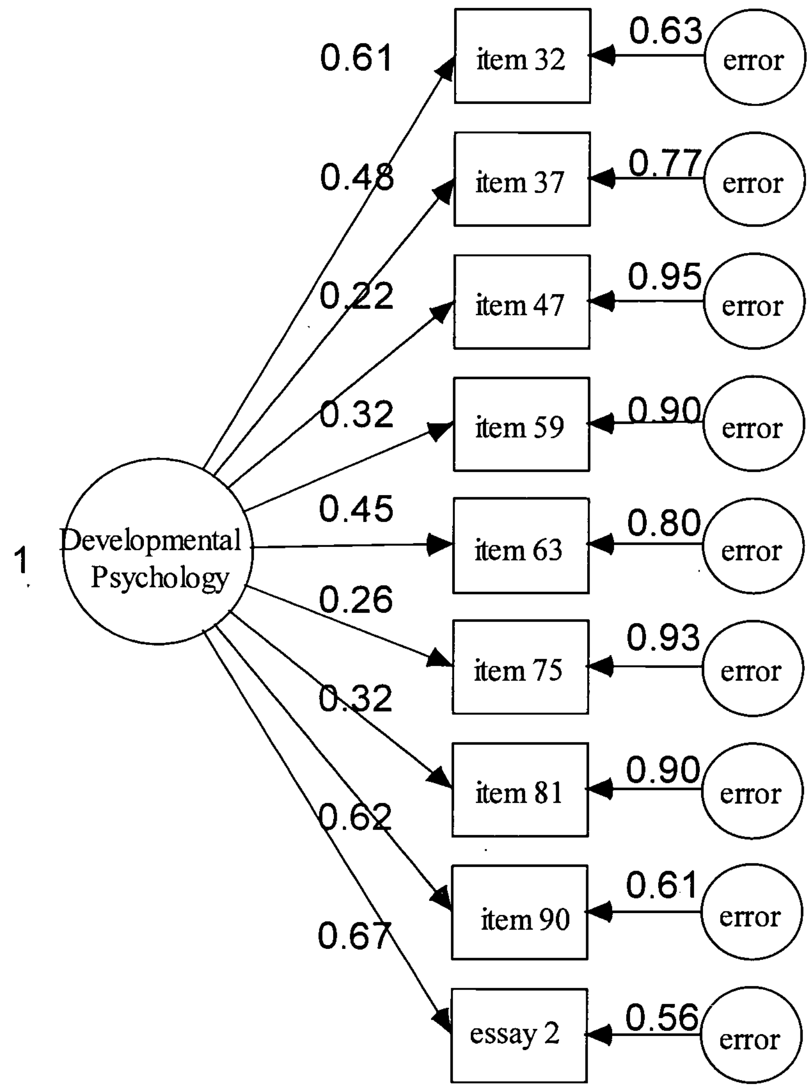
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Developmental Psychology
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0.67
item 32
item 37
item 47
item 59
item 63
item 75
item 81
item 90
essay 2
0.63
0.77
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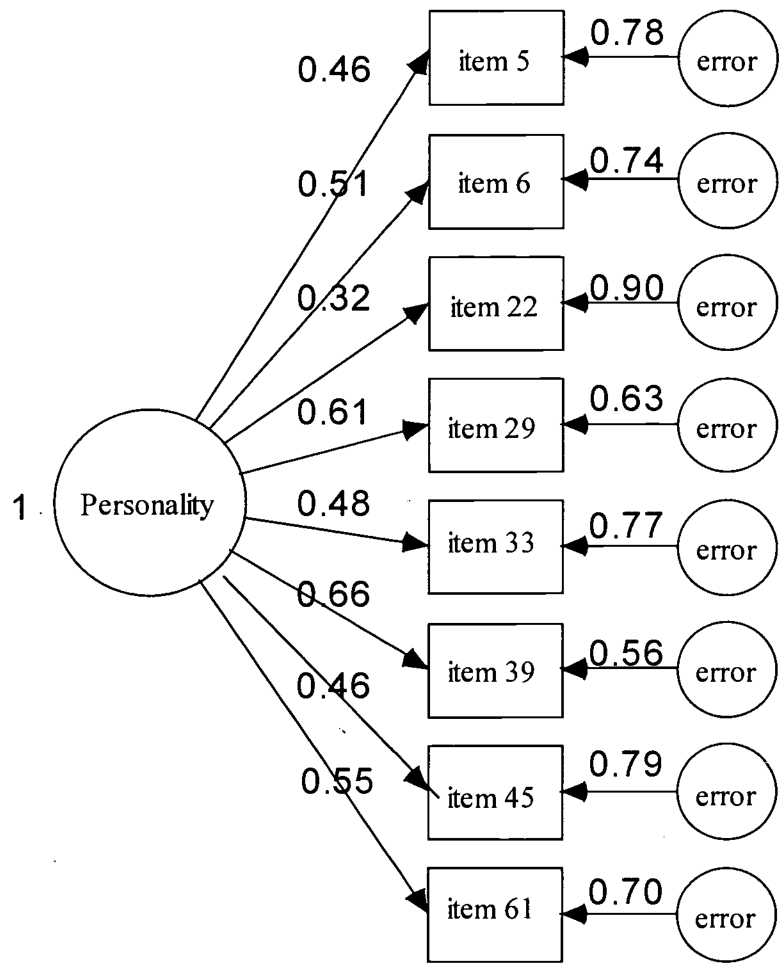
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Personality
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0.61
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item 5
item 6
item 22
item 29
item 33
item 39
item 45
item 61
0.78
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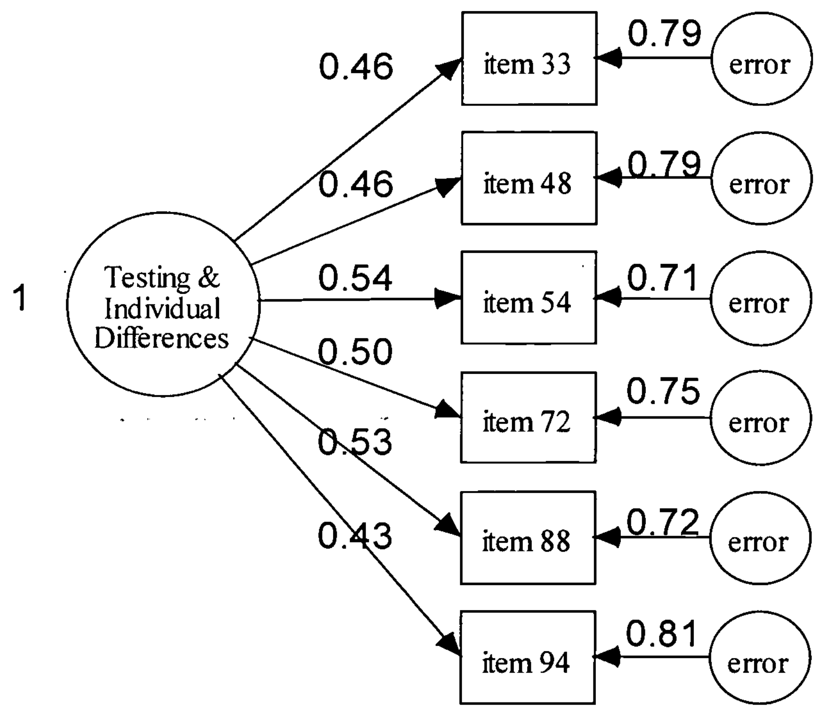
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Testing & Individual Differences
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0.54
0.50
0.53
0.43
item 33
item 48
item 54
item 72
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item 94
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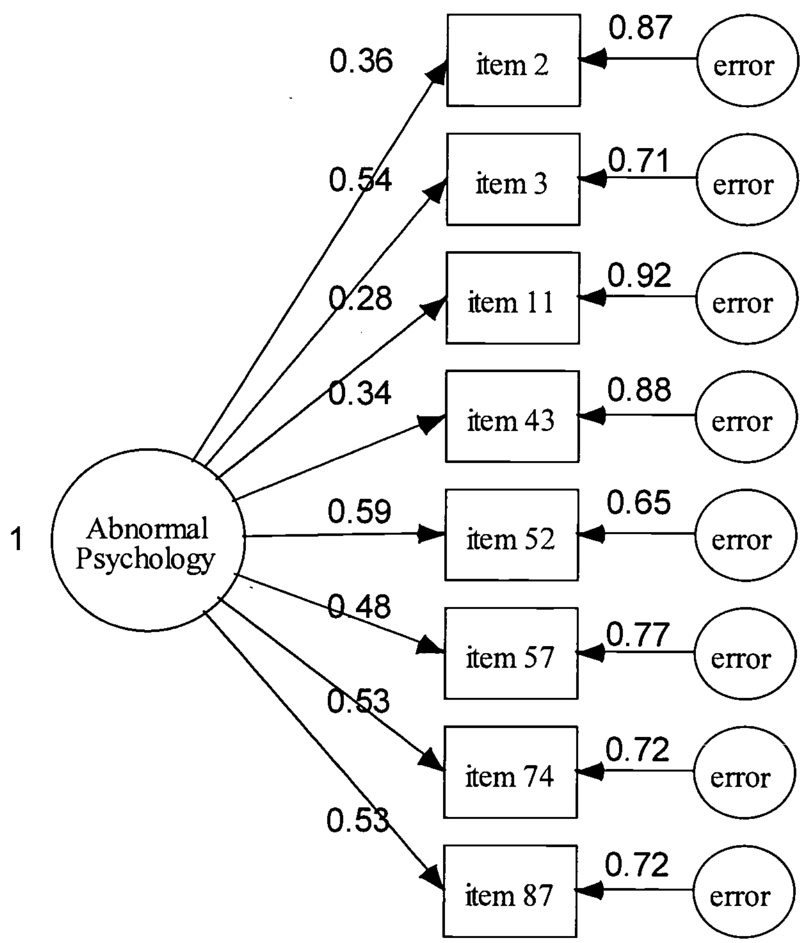
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Abnormal Psychology
item 2
item 3
item 11
item 43
item 52
item 57
item 74
item 87
0.87
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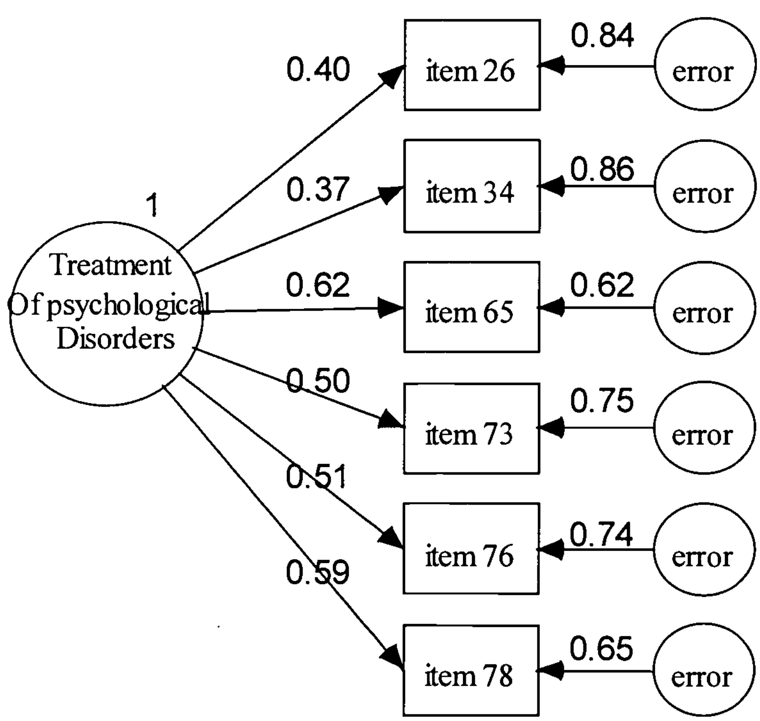
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Treatment Of psychological Disorders
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0.37
0.62
0.50
0.51
0.59
item 26
item 34
item 65
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item 76
item 78
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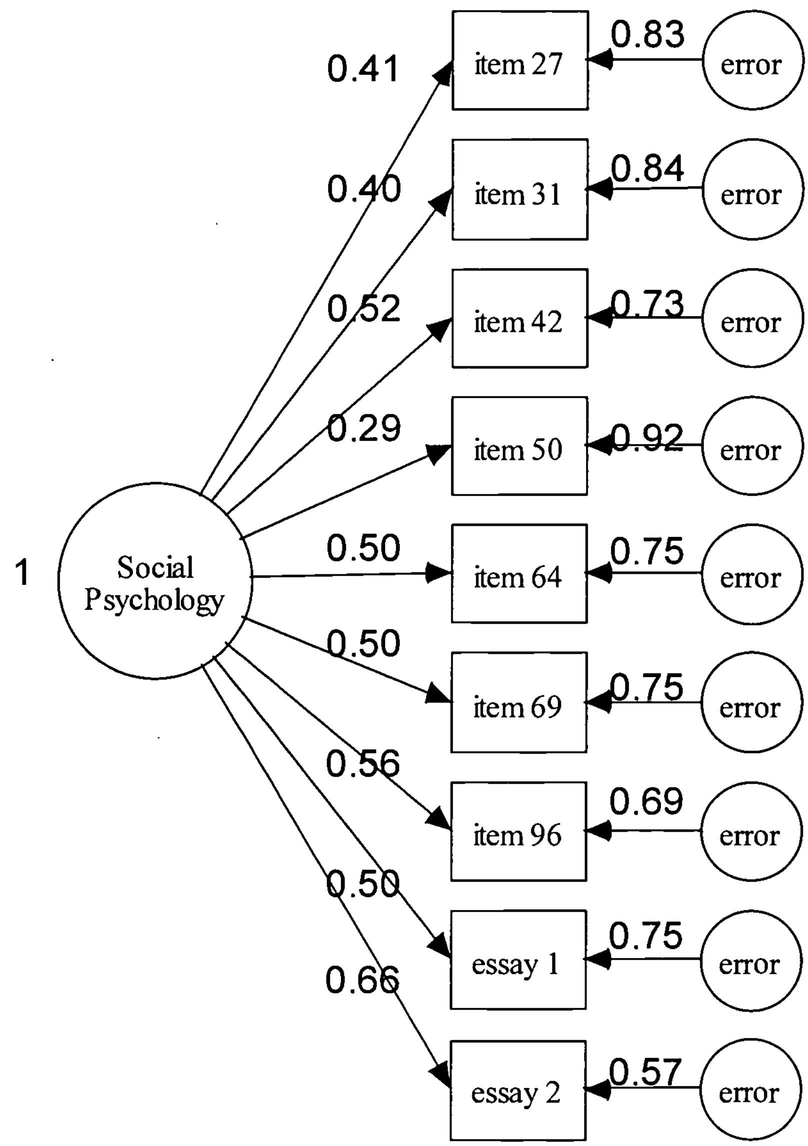
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0.56
0.50
0.66
item 27
item 31
item 42
item 50
item 64
item 69
item 96
essay 1
essay 2
0.83
0.84
0.73
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