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Hypothetico-deductive Thinking Model: Candidate Theory and Mechanism for Didactic Transposition and Teaching of the Experimental Sciences

George N. Nditafon[a*], Emmanuel Noumi[b], Solange Renée B. Nkeck[c], Lawrence N. Nchia[d]

[a]*Corresponding Author: Postgraduate School of Social and Educational Sciences; Faculty of Sciences of Education; University of Yaoundé 1, Yaoundé, Cameroon.*

[b]*Laboratory of Plant Biology: Higher Teachers' Training College; University of Yaoundé 1; BP. 47, Yaoundé, Cameroon.*

[c]*Faculty of Sciences of Education: University of Yaoundé 1; Yaoundé, Cameroon.*

[d]*Postgraduate School of Social and Educational Sciences: Faculty of Sciences of Education; University of Yaoundé 1, Yaoundé, Cameroon.*

[a]*Email: gnditafon@yahoo.com*

[b]*Email: noumikap@yahoo.fr*

[c]*Email: nkeckbidias@yahoo.fr*

[d]*Email: nchiantam@yahoo.co.uk*

Abstract

The aim of this study was to construct and investigate the statistical and psychometric properties of the theorized model of the hypothetico-deductive thinking theory as candidate theory for didactic transposition, teaching and learning of thinking and reasoning. The survey involved 150 students of the Upper Sixth Science and Terminale D classes of both subsystems of education in Cameroon. A five point Likert scale questionnaire type was used to obtain data on students' spontaneous views about the instructional, educational and life skills aspects of the thoracic and vertebral column of the human skeleton and their applicability to problem-solving. Data collected was used to specify a Partial Least Squares Structural Equation Model (PLS-SEM) for the theory. Its statistical and psychometric robustness was investigated using SmartPLS V.2 M3.

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* Corresponding author.

Assessment of the measurement model revealed very significant relationships and very high cross loading regression weights between indicators and their corresponding latent constructs. Also, path model assessment revealed very strong discriminant validity, reliability and Cronbach's alpha statistics. Association between latent constructs were also strongly significant with very adequate predictive relevance and effect sizes. However, the data showed that the model was inadequate in accounting for the variances observed in the dependent constructs judging from the very low variance explained statistic. Within limits of this study, the model furnished convincing statistic and psychometric evidence for further specifications in view of proclaiming the candidate theory as theory for didactic transposition and teaching how to think and reason.

Keywords: Hypothetico-deductive thinking theory; Didactic transposition; Partial Least Squares; Structural Equation Modelling; SmartPLS.

1. Introduction

Scientific literature on cognition, modifiability of cognitive functions, learning and the brain are voluminous. New ideas about ways to facilitate learning can greatly influence the quality of school leavers and even their lives. It has been a worry by scholars that schools have been better at selecting talents than developing same [1]. Many people who have difficulties in school may prosper if new, exciting and creative ways of teaching and learning are embraced. This work is specifically interested in new and relevant ways of introducing students to such traditional subjects as biology, and science. There is hope that new approaches can make it possible for a majority of individuals to develop a deep understanding of important subject matter, acquire thinking, reasoning and process skills for problem-solving. This work seeks to propose a didactic transposition framework tool for teaching and learning the experimental sciences in way that will inspire engagement and action, creativity and innovation in the learner. More specifically, we will explore how thinking skills can be developed in high school students in Cameroon by combining both an objective-based and competency-based perspective of pedagogic approaches in the teaching/learning process. Objective-based pedagogy suggests that teaching and learning occur through the definition of objectives to guide the process during which demonstrable behavioural outcomes are expected. Teaching and learning by objectives is very old and many researchers have proposed models susceptible to improving learner achievement based on pedagogic objectives [2-5] or structuring content into modules [6]. Pedagogic objectives enable the proper definition and delimitation of the package of knowledge to teach. Defining the content of the teaching/learning package calls for both didactic transposition and the selection of an appropriate and contextual didactic model within which the teaching/learning action will operate.

Bloom's taxonomy is very widely known, cited in scientific literature, and often used in guiding the preparation of lessons, teaching of thinking and reasoning skills, and development of competences. On the other hand, Klopfer's taxonomy [5], which is specifically adapted to the teaching of the experimental sciences, appears to be little known and scarcely solicited in the teaching/learning action. From literature review, the teaching of thinking and reasoning are highly recommended as lifelong tools for meeting with the challenges of life in a rapidly metamorphosing environment. In a study on innovative teaching to enhance inferential thinking and communication skills in healthcare professionals Hall [7] concluded that the utilisation of structured classroom debates could constitute a powerful strategy for teaching inferential thinking and enhancing professional communication skills in healthcare providers. In another study Snyder & Snyder [8] concluded that business education instructors at both the secondary and post-secondary levels could enhance students' inferential thinking skills through using instructional strategies that actively engage students in the learning process rather than relying on lecture and rote memorisation by focusing instruction on the process of learning rather than solely on the content. Also Costa [9] and Hyerle [10] argued that inferential thinking should be seen as a basic academic competence, akin to reading and writing, which must be taught. Beyer [11], Hatcher and Spencer [12] suggest that teaching thinking skills is worth considering for the crucial role it plays in teaching, learning, daily life, the workplace, evaluating people, policies, institutions, and the avoidance of social problems. Despite these tremendous recognition of the role of thinking and reasoning in daily life, problem-solving and workplace all these authors fall short of suggesting a framework tool for organising learner's thought and reasoning processes to which learners can readily turn when faced with problems in new contexts.

This research attempts to bridge this gap, through the construction and verification of the validity of a measurement and path model for the hypothetico-deductive thinking framework tool for didactic transposition and teaching based on the modification of Klopfer's taxonomic category C, and the hypothetico-deductive thinking theory proposed by Noumi [13], and elaborated by Nditafon and Noumi [14] and Noumi and Nditafon [15]. This theoretical model which has been shown in previous studies to facilitate learning how to think and reason ought to be modelled and given statistical and psychometric validity as a possible candidate theory and mechanism for didactic transposition and teaching of how to think and reason in the experimental sciences.

Hypothesized theoretical models are investigated by specifying a Structural Equation Model (SEM) and then proceeding to evaluate their statistical and psychometric properties. Chin [16], Haenlein & Kaplan [17], and Statsoft [18], cited by Wong [18] hold that SEM is a second-generation multivariate data analysis method commonly used in marketing that can test theoretically supported linear and additive causal models. Wong [19] adds that SEM has also been employed in many fields, including behavioural sciences [20]; organisation [21]; management information system [22]; and business strategy [23]. With SEM, one can visually examine the relationships that exist among variables of interest in order to improve on the model and its practical applicability. The fact that unobservable, hard-to-measure latent variables can be modelled in SEM makes it ideal for tackling most research problems dealing with human behaviour.

There are two sub-models in a structural equation model:

- The inner (path) model which specifies the relationships between the independent and dependent latent variables; and
- The outer (measurement) model which specifies the relationships between the latent variables and their observed indicators.

In SEM, a variable is either exogenous or endogenous. An exogenous variable has path arrows pointing outwards, and none leading to it. An endogenous variable has at least one path arrow leading to it and represents the effects of other variable(s).

Hypothesis:

Ho: There is lack of adequate statistical and psychometric evidence to validate a proposed structural equation model for a theorised hypothetico-deductive thinking framework model as candidate theory for didactic transposition and teaching of how to think and reason in the experimental sciences for change.

This hypothesis was further operationalised into the following more specific hypotheses:

Ho: $\beta = 0$ for the direct relationships between the driver independent predictor variable (IV) and the intervening dependent predicted latent variables (DV), where β represent the standardised coefficients of Ordinary Least Square (OLS) regression weights between paths.

2. Methodology

This survey was conducted in Government Bilingual High School Etoug-Ebe and Lycée Général Leclerc Yaoundé, Cameroon. The axial part (thoracic and vertebral column) of the human skeleton was used to develop the latent constructs and their corresponding indicators in a process guided by Klopfer's [5] taxonomy of pedagogic objectives and the hypothetico-deductive thinking theory [13-15], [24].

2.1. Sampling

The survey sample consisted of 150 students in all divided into 68 Upper Sixth Science and 82 Terminale D students of both the French- and English-speaking subsystems of the Cameroon education system. The study was conducted from November 2015 to February, 2016.

2.2. Questionnaire

The questionnaire was designed to obtain students spontaneous responses to a researcher-made five point Likert scale on selected categories of Klopfer's taxonomy of pedagogic objectives and the hypothetico-deductive thinking theory.

The first step involved defining the latent variables based on the thoracic and vertebral column that would be used to specify the inner path model of the theorised hypothetico-deductive thinking theory. These latent variables consisted of:

- ability to identify problem-solving characteristics of the Vertebral-Thoracic region of the skeleton (VTC) – the driver Independent Variable or predictor variable);
- ability to take the identified characteristic as know-how in solving a problem (VTS – dependent or predicted variable);
- ability to use the knowledge of (the know-how of the Vertebral – Thoracic region) to decipher and state the problem solved by the identified characteristic (VTP – dependent on VTS). At this stage, VTS becomes the independent (predictor) variable; The process of problem-identification from the

characteristic is by brainstorming and minds mapping;

- ability to find applications of such know-how in other areas of same discipline and other disciplines (interpolation of knowledge and skills) – VTD. In this case the predictors or independent variables are VTS and VTP. VTD is dependent on both of these predictors;
- ability to find similar applications of the know-how in technology including society (extrapolation of knowledge and skills) and solving real life contextual problems – VTT. The predictor IVs VTS, VTP and VTD and VTT is the dependent or predicted variable.

Secondly, 30 observable indicators were developed and organised into a Likert scale type questionnaire for data collection. These were distributed as follows – VTC = 7; VTS = 5; VTP = 6; VTD = 7 and VTT = 5 indicators respectively.

Two alternative methods were used to translate the questionnaire from its original English version into French:

- two parallel independent translations into French were done and then compared to a third equally independent translation by a third person;
- back-translation into the original English version of the French version was done by a fourth person to verify whether the translation was a faithful replica of the original English version.

At the end there were two questionnaire of reference in English and in French.

2.3. Data Collection and Treatment

The completed questionnaire was piloted to readjust the structure, content and to improve coherence and understanding. The final readjusted questionnaire after piloting was administered to the respondents who were asked to complete the questionnaire under the strict supervision of their class teacher and without seeking for assistance from their classmates. The completed questionnaire was collected on the spot thus yielding a 100% return rate.

Data treatment was by use of SPSS V.20 and SmartPLS v.2.0 M3. The completed questionnaire were carefully sorted, coded and entered into the SPSS variable and data spreadsheets. This was re-coded into a Comma Delimited (*.csv) file in order to enable SmartPLS read the file. Next, we specified the model by sketching it using the SmartPLS program, loaded the observed variables onto the appropriate latent constructs and inserted the arrows linking the latent constructs to complete the measurement and path models collectively known as the Structural Equation Model (SEM).

This was followed by an assessment of individual indicator reliability by examining their regression weights on their respective latent constructs. High regression weights implied that there was more shared variance between the construct and its measures than error variance. In this study the criteria of 0.50 recommended by Hulland [23] was used to retain indicators in the model. Additionally, a "Jack-knife-like" procedure recommended by Efron [25], and cited by Ping [26] to remove an observable indicator from the data set, and recalculate the Average Variance Explained (AVE) for the remaining indicators was adopted. This removal-recalculation and replacement process continued repeatedly until indicators that produced optimum AVE improvement were retained.

To assess the significance and relevance of the measurement and structural model relationships, indicator regression weights and path coefficients were generated by running the PLS algorithm and obtained from the SmartPLS Default Report. From the PLS algorithm, R^2 values were read directly and interpreted with respect to the adequacy of the model in predicting the underlying construct of the postulate. R^2 evaluates the portion of the variances of the endogenous variables explained by the structural model. It is an estimate of the quality of the structural model. For the social and behavioural sciences, Cohen [27] suggests cut-off points for R^2 of 2% for small effect; 13% for median effect and 26% for large effect.

After running the PLS algorithm, we proceeded with bootstrapping (a non-parametric re-sampling technique) to test the robustness of the model. An absolute t-value ($|t|$) of ≥1.96 is considered significant with a two-tailed test and an absolute t-value ($|t|$) of ≥.98 is significant with a one-tailed test [28].

This was followed by evaluation of the relevance of the significant relationships or the predictive validity (the Stone-Geisser indicator – Q^2) and effect size (f^2) or Cohen's indicator. The Stone-Geisser indicator (Q^2) was used to evaluate how much the model approaches what was expected of it. The threshold cut-off point for the adequacy of Q^2 is > 0[29]. For Cohen's (f^2), the cut-off points are 0.02, 0.15 and 0.35 for small, medium and large effects respectively [29]. Both Q^2 and f^2 were obtained by using the jack-knifing (blindfolding) module of SmartPLS. The values of Q^2 were read off from the general redundancy values of the model and f^2 from the communalities values of the model represented by the values inside the circles denoting the latent constructs.

Concerning the general evaluation of the reflective model as is the case in this study, the following rules of thumb for evaluating the reflective measurement model are as follows [30]:

- Internal consistency reliability: Composite reliability should be higher that .708 (in exploratory research .60 to .70 is considered acceptable).
- Indicator reliability: The indicator's outer loadings should be higher than .708. Indicators with outer loadings between 0.40 and 0.70 were considered for removal only if the deletion led to an increase in composite reliability and the AVE above the suggested threshold value.
- Convergent validity (AVE): should be higher than 0.50.
- Discriminant validity: The Fornell-Larcker [31] criterion was used to evaluate both measurement and path models.

After assessment of the PLS-SEM model, the limitations of and perspectives for the model were also reported.

3. Results, Interpretations and Discussions

After running the PLS algorithm and deleting indicators with low regression weights (≤.50) to improve on the qualities of the model the following Structural Equation Model was obtained (figure 1):

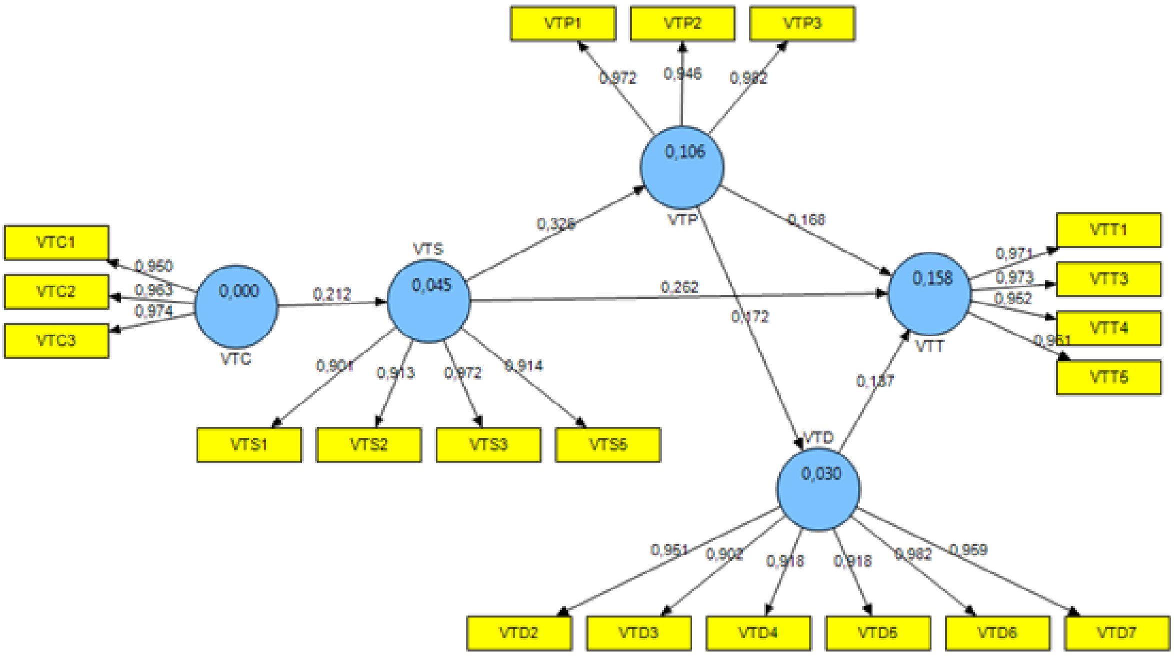

Figure 1: Structural Equation Model for the theorized hypothetico-deductive thinking theory.

Source: Data collected and analysed by Nditafon (2016)

The values on the arrows linking the indicators and their respective constructs are the outer regression weights and those between constructs are the path coefficients. Values inside the circles (latent constructs) are estimates of the squared multiple correlations (R^2) for each dependent construct in the model. R^2 is an estimate of how well the model fits the hypothesized relationship. The R^2 measures a construct's percent variation that is explained by the model. Quality criteria were examined and interpreted in line with defined cut-off rules of thumb in two parts, namely:

- measurement model quality, and
- path or structural model quality.

3.1. Assessing Measurement Model Quality

Results of the measurement model which consists of the relationship between the observable indicators and their respective latent constructs are presented in this section.

3.1.1. Measurement Validity of Reflective Constructs

From bootstrapping (a non-parametric re-sampling technique) using 5000 re-samples, a confirmatory factor analysis (CFA) was achieved as part of the PLS run [32].

The relationship between the constructs and their indicators were all significant with β values varying from

.114622 and t = 16.271888 for VTD3 <- VTD to .391816 and t = 54.202830 for VTC2 <- VTC at *α = .001 and t-critical table value = 2.58, df > 120.* This means that a 100 points change in VTC2 will bring about 39.2 points change in the construct VTC. These results which demonstrate strong convergent validity in the indicators of the theorized measurement model are also reflected in the outer model T-statistics of the bootstrapped results. Both results are displayed in Tables 1(a) and (b).

Table 1(a): Outer Weights (Mean, STDEV, T-Values) at df > 120

						Confidence Interval of Significance		
Indicator/Construct	**Original Sample (O)**	**Sample Mean (M)**	**Standard Deviation (STDEV)**	**Standard Error (STERR)**	**T Statistics (|O/STERR|)**	**α = .05**	**α = .01**	**α = .001**
VTC1 <- VTC	0.336212	0.336211	0.004759	0.004759	70.644556			***
VTC2 <- VTC	0.391816	0.392194	0.007229	0.007229	54.202830			***
VTC3 <- VTC	0.311305	0.311049	0.006069	0.006069	51.295098			***
VTD2 <- VTD	0.195096	0.194502	0.004746	0.004746	41.111123			***
VTD3 <- VTD	0.114622	0.115118	0.007044	0.007044	16.271888			***
VTD4 <- VTD	0.153685	0.154374	0.005217	0.005217	29.458244			***
VTD5 <- VTD	0.207503	0.207113	0.005356	0.005356	38.741634			***
VTD6 <- VTD	0.206006	0.205772	0.003312	0.003312	62.206581			***
VTD7 <- VTD	0.184601	0.184770	0.003561	0.003561	51.844692			***
VTP1 <- VTP	0.352771	0.353139	0.002480	0.002480	142.222030			***
VTP2 <- VTP	0.332389	0.331974	0.003004	0.003004	110.663584			***
VTP3 <- VTP	0.349164	0.349325	0.002093	0.002093	166.845817			***
VTS1 <- VTS	0.234898	0.234775	0.003211	0.003211	73.157078			***
VTS2 <- VTS	0.273702	0.273821	0.002627	0.002627	104.172764			***
VTS3 <- VTS	0.293567	0.293589	0.002230	0.002230	131.668481			***
VTS5 <- VTS	0.276943	0.277299	0.003069	0.003069	90.232082			***
VTT1 <- VTT	0.283270	0.283381	0.003145	0.003145	90.067738			***
VTT3 <- VTT	0.260637	0.260066	0.002935	0.002935	88.789402			***
VTT4 <- VTT	0.265474	0.265885	0.002522	0.002522	105.254797			***
VTT5 <- VTT	0.227345	0.227452	0.002324	0.002324	97.842658			***

** t is significant at α = .05*

*** t is significant at α = .01*

**** t is significant at α = .001*

Source: Data collected and analysed by Nditafon (2016)

Table 1(b): Outer Model T-Statistics

Observed Indicators	**VTC**	**VTD**	**VTP**	**VTS**	**VTT**
VTC1	329.489249				
VTC2	495.505278				
VTC3	670.664264				
VTD2		250.240652			
VTD3		124.443893			
VTD4		145.399270			
VTD5		198.193974			
VTD6		1402.921263			
VTD7		373.596131			
VTP1			657.906013		
VTP2			238.970321		
VTP3			941.031050		
VTS1				205.456849	
VTS2				202.109087	
VTS3				931.728552	
VTS5				225.461234	
VTT1					652.463487
VTT3					441.430221
VTT4					351.973954
VTT5					329.699976

Source: Data collected and analysed by Nditafon, (2016)

3.1.2. Discriminant Validity of Indicators

In this section results of discriminant validity of indicators were read from table and presented as indicator cross loading.

3.1.2.1. Cross Loadings

Discriminant validity was demonstrated by comparing the cross loadings with the absolute value of 0.100 distant from the loadings on the primary construct. For example, in Table 2, the VTC1 indicator loads with .949928 onto the VTC latent variable, but loads onto other constructs with values not greater than .300 (see loading between VTC1 and the construct VTD, VTP, VTS and VTT in Table 2. The strong loading on VTC is an indication that VTC1 is more strongly correlated with VTC2 and 3 than it is with other indicators in the table. A similar behaviour is seen between all the other indicators and their corresponding latent constructs. These results proof that there is strong discriminant validity between indicators in the model.

Table 2: Cross loadings of indicators on constructs

Indicators	VTC	VTD	VTP	VTS	VTT
VTC1	**0.949928**	0.229922	0.065703	0.195713	0.105136
VTC2	**0.962887**	0.161071	0.091025	0.228082	0.140529
VTC3	**0.974440**	0.221229	0.100015	0.181215	0.143689
VTD2	0.221216	**0.951327**	0.144299	0.093642	0.215387
VTD3	0.162928	**0.902244**	0.087657	0.034341	0.123924
VTD4	0.153141	**0.918428**	0.163724	0.049517	0.124102
VTD5	0.218590	**0.917983**	0.222158	0.110514	0.166558
VTD6	0.197121	**0.982051**	0.169181	0.091105	0.212127
VTD7	0.205564	**0.959048**	0.149956	0.092477	0.191585
VTP1	0.113281	0.200580	**0.971557**	0.302991	0.277479
VTP2	0.058986	0.132328	**0.946161**	0.343074	0.228758
VTP3	0.083976	0.163967	**0.981685**	0.301636	0.294078
VTS1	0.155360	0.031881	0.240204	**0.900839**	0.293861
VTS2	0.182806	0.076652	0.298684	**0.912690**	0.322594
VTS3	0.228543	0.096028	0.334479	**0.972265**	0.311083
VTS5	0.209283	0.115286	0.324528	**0.914142**	0.288608
VTT1	0.152138	0.183192	0.303198	0.343464	**0.971448**
VTT3	0.145449	0.197797	0.271466	0.305534	**0.972981**
VTT4	0.126974	0.210473	0.239098	0.330456	**0.952079**
VTT5	0.089850	0.130218	0.248473	0.281156	**0.960967**

Source: Data collected and analysed by Nditafon (2016)

3.2. Assessing Path Model Quality

The path model represents the structural model and is concerned with the relationship between latent constructs.

3.2.1. Average Variance Extracted (AVE)

By comparing the square root of the average variance extracted (AVE) to the correlations with other constructs, discriminant validity was also demonstrated. *The square root of the AVE were used and not the AVE directly* [17]. Like cross loading, the concept that justifies the use of the square root of the AVE in judging discriminant validity is that the correlation of the construct with its measurement indicators should be higher than its correlation with any other construct [33]. Examination of the diagonal values showed that each value was greater than the off-diagonal value for the same row and column, thus proving strong discriminant validity which confirmed the choice of retaining the different items on the scale in the final model. These results are displayed in Table 3 with the square roots of the AVE in bold along the diagonal.

Table 3: Latent construct correlations and square roots of AVE

	VTC	**VTD**	**VTP**	**VTS**	**VTT**
VTC	**.962470**				
VTD	0.209283	**.938924**			
VTP	0.088890	0.171994	**.966584**		
VTS	0.211580	0.088587	0.326241	**.925401**	
VTT	0.135141	0.188926	0.276604	0.328573	**.964406**

Source: Data collected and analysed by Nditafon (2016)

3.2.2. Composite Reliability and Cronbach's Alpha

Reliability is the degree to which a scale will yield consistent and stable measures over time. This applies mainly to reflective indicators. In the theorized model in this study all the constructs have Cronbach's alpha > .90, Table 4. These are clearly above the > .60 threshold value acceptable for exploratory studies such as these. This suggests that the model has high internal consistency and is therefore susceptible to yield consistent and stable measures over time.

Table 4: Composite Reliability and Cronbach's Alpha

Constructs	**Composite Reliability**	**Cronbach's Alpha**
VTC	0.974179	0.960368
VTD	0.978083	0.973258
VTP	0.977085	0.964722
VTS	0.959722	0.943876
VTT	0.981551	0.974969

Source: Data collected and analysed by Nditafon (2016)

Despite the high Cronbach's alpha (> .9) in this model, Reference [31] suggest that a better statistic for estimating structural model reliability is the measure of composite reliability. This is so because it offers a better estimate of variance shared by the respective indicators and because it makes use of the indicator regression weights obtained within the nomological network [34]. Additionally, Cronbach's alpha tends to be underestimated in a PLS model. Cronbach's alpha assumes that all indicators are equally reliable with equal outer loadings on the construct. As a result of these limitations, it is technically more appropriate to apply a different measure of internal consistency reliability [29]. In addition to Fornell and Larcker's composite reliability criteria, we also relied on AVE discussed in the preceding section. In this study the composite reliability coefficients of the latent constructs ranged from .959722 to .981551 (see Table 4), which largely meets the standard of >.70 as suggested by [31].

Variance Explained (R^2)

R^2 evaluates the variance of the dependent construct explained by the model. It provides information about the quality of the hypothesized model. Examination of the R^2 values in this research revealed the following information about the quality of the model:

- The construct VTS explained 4.50% of the model (R^2 = .045). This is a small effect according to Cohen's [27] threshold value of 2% for a small effect and 13% for a moderate effect.
- The construct VTD explained 3.00% of the model (R^2 = .030). According to Cohen [27], this is also a small effect.
- VTP explained 10.60% - equally a small effect and VTS explained 15.80% - a moderate effect by Cohen's criteria.

These statistics seem to suggest that, the model has a poor quality, though this cannot be conclusive as many other alternative competing models are possible and can be specified. However, when we take the postulated stages of the theorised model together the entire process from latent construct VTC, VTS, VTP, VTD and VTT explained a total of 29.4% of the model. This is above the threshold cut-off value of 26% for a large effect suggested by [27]. Based on this therefore, it can be said that within limits of the study, the model cannot be rejected outright.

3.2.3. Path Coefficients

The path coefficients are causal statistics of the effect of one construct on the other.

Table 5: Path coefficients of the relationships between constructs in the model

Constructs	**VTC**	**VTD**	**VTP**	**VTS**	**VTT**
VTC				0.211580	
VTD					0.136901
VTP		0.171994			0.167666
VTS			0.326241		0.261746
VTT					

Source: Data collected and analysed by Nditafon (2016)

Examination of the path coefficients in Table 5 revealed that all paths have a positive influence between constructs with VTS → VTP being the strongest (path coefficient = .326241). This high value justifies the fact that deciphering the problem solved by the possession of a particular characteristic is essential in finding analogues of similar applications of the know-how in other disciplines and in technology including society. This equally justifies the logic behind the theorized model which suggests that after considering the characteristics of an organism as solution or know-how to solving a problem(s) (VTS), thinking proceeds by brainstorming and mind mapping to decipher and state the problem solved (VTP) by the perceived know-how (VTS). These path coefficients are not correlations but simply an estimation of how much the mean of the endogenous construct will change as a result of a change by one standard deviation on the mean of its influencing exogenous construct. Where the value of the path coefficient is positive the change is also positive and where the value is negative the corresponding change is reciprocal.

3.2.4. Stone-Geisser (Q^2) Predictive Relevance and Cohen's (f^2) Effect Size

To establish the effect size of path influences on latent constructs (f^2) and the predictive relevance (Q^2) of the model, a jack-knifing analysis was conducted and the following Q^2 and f^2 statistics were obtained for each latent construct by reading the general redundancy and communality estimates in the jack-knifed output as displayed in figure 2.

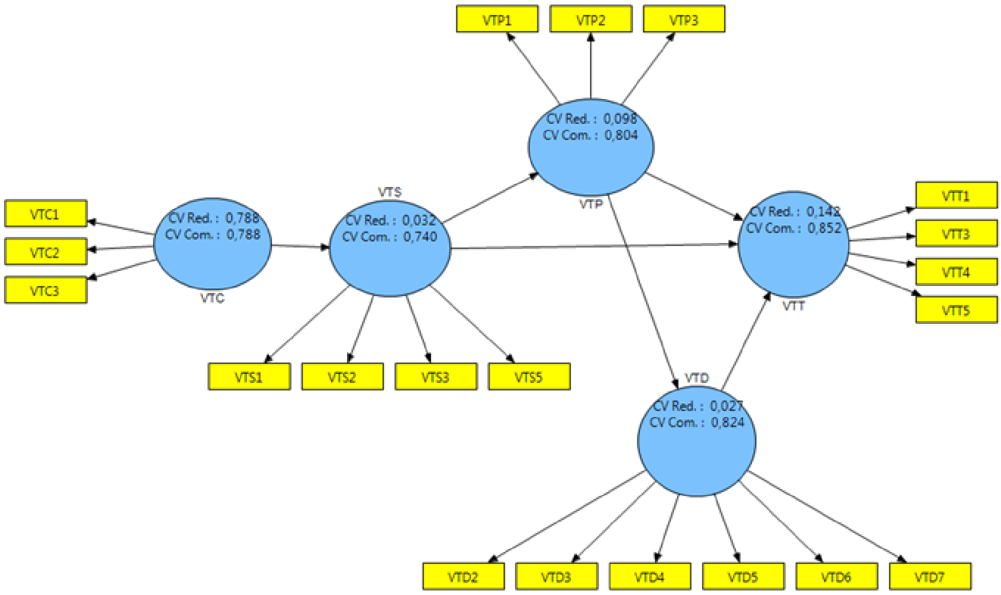

Figure 2. Blindfolding (Jack-knifing) output showing Q^2 and f^2 estimates for the predictive relevance and effect size of the model.
Source: Data collected and analysed by Nditafon (2016)

Examination of figure 2 provide evidence that the observed values are well reconstructed and the model has predictive relevance since the Stone-Geisser statistic in all the cases is >0. The diagram equally provide evidence that the predictor latent constructs have a very strong effect at the structural level since in all the cases Cohen's (f^2) effect size is well above the threshold value of .35 for strong effect.

3.3. Hypotheses Verification

Ho: β = 0 for the direct relationships: VTC → VTS; VTS → VTP; VTS → VTT; VTP → VTT; VTP → VTD and VTD → VTT), where β represents standardised coefficients of Ordinary Least Square (OLS) regression weights between paths.

To verify these hypotheses, we examined the path coefficients and the T-statistic in the bootstrapped run to appreciate the level of significance of the direct relationships between the constructs:

3.3.1. Path coefficients and Model T-Statistic in Bootstrapping

Path coefficients on their own are not very informative as to whether the predicted variations are significant or not, but sure do provide information that associations exist between the different regions of the model. To find out whether variations in path coefficients are significant, we turned to the T-statistic – Table 6.

Table 6: Inner Model T- Statistic against Level of Significance

	Original Sample (O)	**Sample Mean (M)**	**Standard Deviation (STDEV)**	**Standard Error (STERR)**	**T Statistics (|O/STERR|)**	**Confidence Interval of Significance**		
						α = .05	**α = .01**	**α = .001**
VTC -> VTS	0.211580	0.211747	0.015316	0.015316	13.814352			***
VTD -> VTT	0.136901	0.136332	0.015992	0.015992	8.560765			***
VTP -> VTD	0.171994	0.171965	0.014193	0.014193	12.118478			***
VTP -> VTT	0.167666	0.167713	0.011237	0.011237	14.920489			***
VTS -> VTP	0.326241	0.325203	0.013558	0.013558	24.062398			***
VTS -> VTT	0.261746	0.262972	0.014123	0.014123	18.533483			***

** Significant at critical table value t > 1.96 two tail*

*** Significant at critical table value t > 2.34 two tail*

**** Significant at critical table value t > 2.58 two tail*

Source: Data collected and analysed by Nditafon (2016)

Table 6 shows very high levels of significance in associations between direct paths in a two-tail test for example:

VTC → VTS: $\beta = .211580$, $t = 13.814352$, $\alpha < .001$ and t-critical table value = 2.58, df > 120;

VTD → VTT: $\beta = .136901$, $t = 8.560765$, $\alpha < .001$ and t-critical table value = 2.58, df > 120.

The same results are observed for the rest of the direct paths all at t-critical table value = 2.58, $\alpha = .001$ and df > 120. As a result, the **Ho = 0** is rejected in favour of **Ho ≠ 0**.

4. Limitations

The results of this study make several contributions to didactic transposition and teaching of the experimental sciences. However, despite these contributions, the findings must be viewed in the light of certain limitations that cannot be under looked, namely:

- only five latent constructs were chosen for this study whereas many other constructs could have been included such as the social background, prior school type attended by the students such as Francophone versus Anglophone school systems;
- limitation in scope since other alternative competing models such as formative or combined reflective and formative models do exist and should be explored to improve on the strength of the final conclusion;
- the low values of the total variances explained for some latent constructs such as VTS (4.5%) and VTD (3.0%) could be related to the quality of the data collection instrument and indicators, all of which were researcher-made and should therefore be subject to further improvement and refinement. This could also be due to the limited scope of the work since competing alternative models were not investigated;
- the SEM method and SmartPLS software used, only consider linear relationships between the proposed latent variables. Presumed relationships especially in the social sciences are not often linear in reality, thus further in-depth research using other more powerful software is needed to give the model greater confirmation;
- the study only explored the theoretical model on students in the didactic situation which should actually involve all components of a didactic situation, namely – student, teacher, content knowledge and the pedagogical situation. Future studies should be expanded to include these other components of the didactic situation.

5. Conclusion and Perspectives

In perspective work is ongoing to investigate alternative competing models and to conduct a more stringent hard modelling using Covariance-Based Structural Equation Modelling (CB-SEM) with more rigorous statistical assumptions and conditions with the view of generalizing the results.

In conclusion and within the limits of this study, the hypothetico-deductive thinking model fits the data and therefore there is adequate statistical and psychometric evidence for proclaiming it an excellent candidate theory for didactic transposition, teaching and learning in the experimental sciences.

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