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Research Article

Blended-Learning-Environment for Mathematical Skill Acquisition among Higher Education Learners Using Principal Compound Analysis and Structural Equation Modelling

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ARTICLE INFO	ABSTRACT

The skills like observing, modelling, interpreting and utilizing the solutions for problem solving are learnable for the higher education learners. Mathematical-knowledge leads to cognitive development for HELs. Inhaling capacity of the above-mentioned skills among learners is possible through their cognitive development. Learning environment is one of the most key factor for Mathematics-learning. Based on sensitivity about attitude, engagement and formal and informal learning environments (for mathematics-learning), about two hundred and ten primary data had been collected and taken for this research work. Principal compound analysis machine learning technique has been opted to reduce the dimension. Insights of dimensionally reduced data has been discussed scientifically, especially about the learning environments, using Structural equation modelling. Learners' sentiment about the formal (or physical) learning environment has been observed from SEM with mediation effect. This effect on physical learning environment from performance through (social media-learning) informal Learning is 10.9%. But the absence of social media-learning in the path analysis is showing 1.8% effect on formal learning environment. Results are indicating clearly, that the integration of informal aspect (Social Medias) in learning process is immediate need. Educational stake-holders should be promoted to adapt the innovation techniques by every educational institutions' policy makers. Blended-learning environments could be created to improve the performance of learners in Mathematics subject. Integration of physical (formal) and virtual learning (learning through social media) is possible by the collaborative effort between educators and industries. The next generation learning could be enhanced through integration of three dimensional projectors in the form of internet application with learning facilities, which could be useful for rural area learners also.

Keywords: Principal compound analysis, Structural equation modelling, Mathematical-learning environments, formal and informal learning.

1. Introduction

Up gradation of any system is based on reviewing the research-based solutions (or ideas), accepting and transforming through iterative processes. Iterations with tiny tuning of factors which are in present progress the continuum. Measurements or assessments of continuum is possible with mathematical, statistical and machine learning modelling. Regression, classification ML models and structural equation modelling are the indicators of actual facts and alternative solutions of real-life problems for varied-disciplines.
Advancement in education sectors is possible, with the organised way of approaching, towards maximum and possible aspects of teaching-learning process. After COVID-19 pandemic there is vital need of adopting blended learning in higher education sector. It has been observed that the learners were manifesting positive-behaviour,

due to physical learning environment. The knowledge was derived through decision tree classification algorithm (Bhuma Devi S. , 2023). Higher education learners' learning-behaviour, collecting the study-materials was more among the learners' preference for online streaming way of learning. This analysis had been done through conditional probabilistic approach (Bhuma Devi & Jain, 2021). Average performance of first year engineering students were improved in online assessment. This observation was derived using simple linear regression for the subject engineering mathematics II (Bhuma Devi & Jain, Predictive Model of Learning Analytics for On-Ground Verses Online Assessment, 2020).
Optimistic outlook among higher education learners, about learning mathematics is the outcome of their self-assurance, interest and functionality. This was noticed through structural equation modelling (Otoo & et.al, 2018). Learning-environments are significant factor in mathematics-learning, through which the learners' abilities could be enhanced. An attempt has been made to discuss about the essentiality of reconciled learning environment using structural equation modelling recursively.

1.1 Motivation

Optimised utilization of training and learning process is possible with inclusion of physical and dynamic-virtual learning environments. Necessity of such environments for mathematical-learning has increased in higher education sectors. Basic and essential skills like observing, analysing, interpreting, deriving insights from data (or first-hand information) and using the knowledge finding solutions for real-life problems are creating cognitive development among higher education learners. In the process of Mathematical skill-acquisition, utilizing the proper and suitable learning environment for applied-mathematics subject is the key element. Based on the HELs perceptions about attitude, engagement, classroom learning, availing help from private tutorial centres and social media learning, effects of learning factors and their performance in mathematics subject will lead to formation of feasible blended learning-environment.
The research questions for this paper will be

1. What and how Principal component analysis is significant for the investigation about Mathematics learning-environment?
2. What are the important features (or elements) could be included (or modified) in the learning-environment of higher education learners for mathematics subject?
3. Which path analysis is significant for self-effort Mathematics-learning in the structural equation modelling?
4. How modification could be inserted in the existing learning-environment for mathematics-learning?

2. Related work

The learning-environments are nothing but overall learning ecosystem. In which all the features of teaching, learning and training will be incorporated as per necessity of educational-stake holders. Higher education learners are in the stage to take on mathematical language, for the derivation of feasible research-based solutions in their specialization areas. Prerequisite assessments, learners' background, learners' learning styles, their difficulties and expectations from learning environments and few more factors have been studied scientifically in the following reviews and research articles.
(Ozerem & Akkoyunlu, 2015) investigated about the pre and post-test achievements of fifty-five seventh grade learners in Mathematics with their learning styles and environments. As per the requirements of leaners' learning style (visual-auditory-kinesthetics), learning environments were designed. The impact of designed-learning environments was positive in post-test results.
(Tang & Chaw, 2016) made inquiries about the significance of digital literacy among the higher education learners in their effective learning-processes. The data had been collected from 176 HELs through the learning management systems (LMS). Out of which 161 learners' responses had been considered for modelling purpose. Exploratory Factor analysis and Confirmatory factor analysis and structure models had been used to analyse the data. The authors concluded that the self-directed learning is the main aspect which should be followed by learners otherwise the educators should motivate the learners in that direction of effective blended-learning.
(Kintu & et.al, 2017) inquired into the effective blended learning-environment based on a survey. Nearly 238 students were participated in this study. The learners' attitude, self-regulation, age, gender, and digital knowledge, learning environments' features and quality of LMS had been considered as independent variables and learners' acceptance, knowledge and performance had been considered as the dependent variables. Multi-linear regression model was not indicating any significance in the learners' performance based on other variables in this study. At the same time many important insights related with learners' characteristics and features of learning-environments, were intimated to consider while preparing the effective blended learning environments for university learners.
(Prameswari & Budiyanto, 2017) reviewed the reputed educational research articles from 2007 to 2015. The researchers have come to the conclusion that effective learning results from suitable instruction and structured classroom management. The ability of educators to generate novel knowledge, the educational institutions' support, and the capacity of learners to engage with one another are the three key components that make up an effective learning environment.

(Bendangnuksung & Prabu, 2018) proposed deep neural network ML model to predict the HELs' performance. The dataset had been taken from Kaggle website, which was having 500 students' educational information. Nearly sixteen nominal and four numeric data descriptions were presented in the dataset. Decision Tree (J48), Artificial Neural Network (ANN), Naive Bayes (NB) models were compared with proposed DNN model. The accuracy of DNN was high among all other models' accuracy.

(Wang & Liu, 2019) discussed about the necessity of students' contribution as a service to the society. The Roger's psychological and student-centric (or people-centric) counselling, will lead to the students' overall development as a cultured, scientific, self-esteemed and self-motivated beings.

(Valtonen & et.al, 2021) analysed the necessity of modified learning-environment for the higher education learners. In response to the open-ended questions, about 230 HELs have shared their thoughts. The researchers had gathered data from HELs regarding the current learning environment with the use of an additional questionnaire. The findings suggest that both physical and virtual learning resources should be available in the learning environment. The expectations of university students in this study were for experiential learning in groups with a teaching team for informal learning on campus and virtual learning resources for knowledge growth.

(Rong & Mononen, 2022) explored about the identification of Mathematical learning difficulty learners of seventh grade in Tibet. There were thirty students in this experiment from rural and urban area. Mathematical error pattern identification test had been conducted to find the visual-spatial, comprehension, transformation, relevance, fact, procedural, measurement and presentational errors among the learners (in their mathematical tasks). It was observed that, in general fact, comprehension errors were more among the learners. The fact and relevance errors had been found among girls. The comprehension errors were found among rural learners. MEPIT was significant assessment tool for knowing MLD learners.

(Talan & Kalınkara, 2022) investigated that the use of Metaverse in education, with thirty-four students of computer department from a state University in the Southeast Anatolia region of Turkey. The pros and cons have been discussed in this research work about the Metaverse-Learning environment. The students were accepted that they will be benefitted in terms of knowledge-acquisition with Metaverse-Learning environment. At the same time, they admitted that there will be distractions with such kind of environments. Authors concluded that the teachers also should be trained to deal with updated learning processes for Metaverse environment.

(Mitra, 2023) analysed the significance of metaverse in education. Author proposed a metaverse learning and training model to avail the blended-learning for learners and corporate people. The author mentioned about the potential for mutual interaction and knowledge exchange between Avatars and the real time participants from distinct places.

(Buragohain & et.al, 2023) analysed and discussed about the learning environments, with the systematic literature review (the research articles after COVID-19 from the renowned journals regarding learning environments, case studies about the immersed technology courses and digital twin creation for the pig farms in Thailand (for gamification-learning). Researchers concluded that the integration of Virtual Reality, Augmented Reality for learning purposes will be maximising the learning experiences along with tradition learning environments.

Based-on the above studies the following objective has been obtained to investigate scientifically.

2.1 Research Objective

To assess the importance of blended learning environments (Physical, Virtual and Inclusive of social media for taking additional training) in acquirement of mathematical-skills among higher education learners.

3. Methodology

The research process and methodology could be observable from the following Figure 1. Google form has been used as a tool for collecting data. Nearly two hundred and ten HELs have given their response from an education trust from Thane, Maharashtra in the first half of 2023. Mainly their attitude, engagement with mathematics subject, perceptions about classroom, and coaching, social media in learning and deep-learning factors had been collected through questionnaire, which were in thirty-two smaller dimension (LPCL, LPEL, LAM, LEM, SML and LF). Bachelors of Commerce, Management, Science, Finance and Engineering students have given their response.

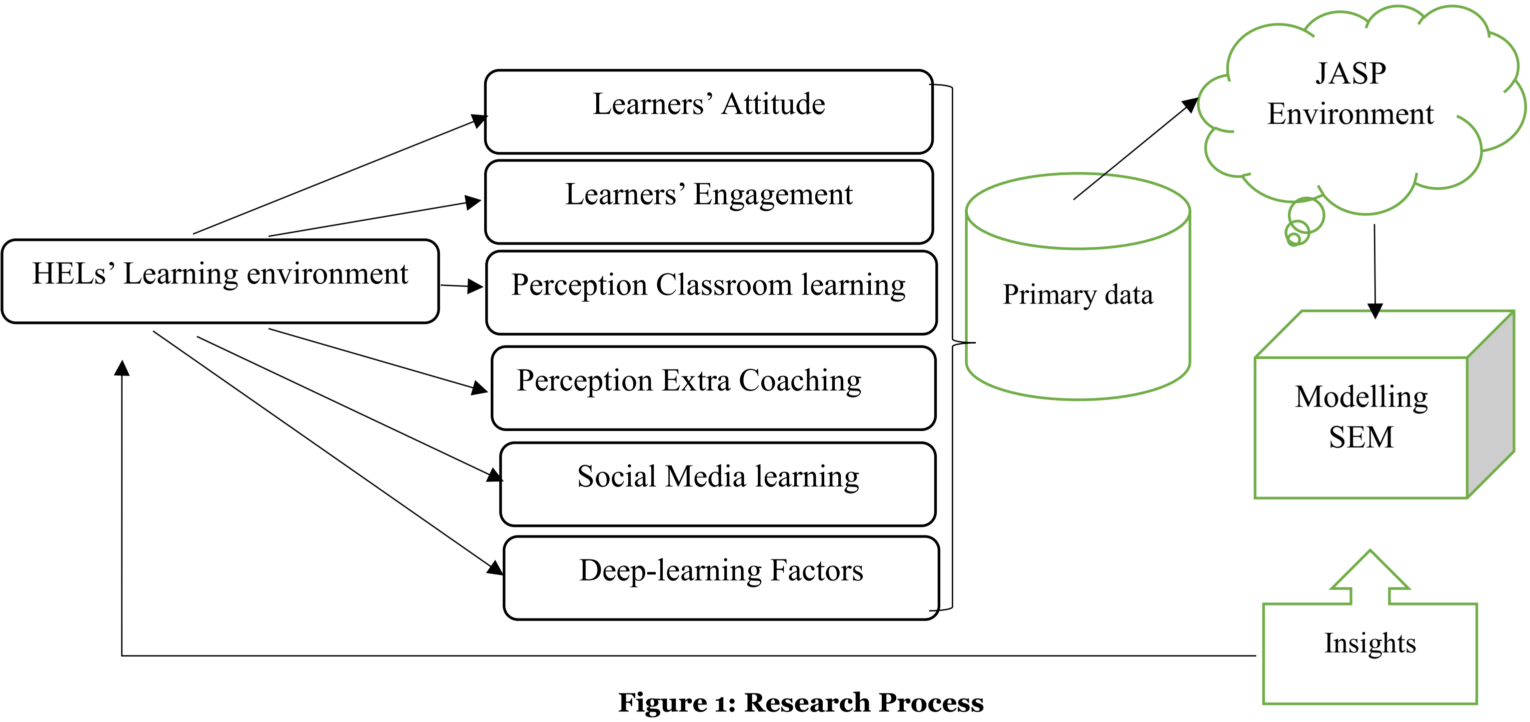

Figure 1: Research Process

3.1 Principal Compound Analysis (Unsupervised Machine learning clustering Algorithm)

The collected data has been pre-processed for analysing the data. The categorical data had been changed as numerical scale data. Cleaned data has been modelled in JASP environment. The formation and utility of principal compounds are essential to understand mathematically and statistically. Based on the variance, mathematical representation of PCs' are the linear functions, which could be written, using the following mathematical representations.

$\alpha_i' x = \alpha_{i1}x_1 + \alpha_{i2}x_2 + \cdots + \alpha_{in}x_n = \sum_{j=1}^{n} \alpha_{ij}x_j$, where i = 1, 2, 3, …., m and m ≤ n.

In which "m" will be the numbers of PCs and "n" is the number of variables. The linear transformations $\alpha_i' x$ of PCs will be uncorrelated with optimized variance. Uniqueness values of the variables in PCA will be conforming the above fact statistically.

Consider a random variable "x" has the covariance matrix Σ and the k[th] PC is $z_k = \alpha_k' x$. The diagonal elements and the non-diagonal elements of Σ will be the variance and covariance respectively. α_k is the Eigen vector of Σ corresponding to a large Eigen value λ_k. The length of α_k is $\alpha_k' \alpha_k$ =1 and the variance of z_k is λ_k. The following could be understandable by the following derivation.

The PC $z_k = \alpha_k' x$ is with α_k vector which maximize $var[\alpha_k' x] = \alpha_k' \Sigma \alpha_k$, in order the evaluate this, normalised constrain is $\alpha_k' \Sigma \alpha_k = 1$ could be considered. By introducing the Lagrange multiplier the objective function could be written as follows.

$$Maximize\ [var[\alpha_k' x] - \lambda(\alpha_k' \Sigma \alpha_k - 1\,)]$$

By performing partial differentiation with respect to α_k' and equating it to zero and solving,

$$\Sigma \alpha_k - \lambda(\Sigma \alpha_k\,) = 0$$

Or

$$[\Sigma \alpha_k - \lambda I_m]\alpha_k = 0$$

Which gives the larger Eigen value of Σ as λ and the corresponding Eigen vector is α_k. Therefore, the conclusion is $var[\alpha_k' x] = \alpha_k' \Sigma \alpha_k = \lambda_k$ (Jolliffe, 2002).

In this research work the PCA is giving the four major principal compounds using the matrix linear transformations. Twenty five cross two hundred and ten matrix has been reduced to four cross four matrix. And the model fit is $\frac{\chi^2}{df} = modelfit = 2.54$, which is less than 5, therefore the model is reliable for PCA (Alavi & et.al, 2020).

Motivation behind the investigation about the learning-environment is the dimensionally-reduced data through PCA. In the next part Exploratory factor analysis has been carried using SEM to bring the measurable changes in the learning-environments of mathematics subject for the higher education learners.

3.2 Structural Equation Modelling for Data Analysis

The processed-data had been modelled using structural equation modelling in JASP environment. Measurement models have created, model fit also checked which is $\frac{\chi^2}{df} = modelfit = 1.87 < 5$, good fit (Alavi & et.al, 2020). Multi-level and multivariate analysis have been performed to understand the relations among

the unobserved (or latent or constructs) variables. Independent latent variables' (exogenous variables') effects on endogenous variable (LPCL in Figure 2, 3) have been measured. That is the non-linear relations and its' effects among the latent variables have been studied and interpreted. The factor loadings have been measured using path analysis between the constructs of this work.
Linear and non-linear analysis are possible in SEM. Every measurement model (latent variables) is the representation of linear model. Exogenous variables' effects on endogenous variable (or variables) are the non-linear, which is recursive in nature. The following equations are mathematical representations of linear and non-linear relations in SEM with variables, constructs, exogenous and endogenous variables.
Consider $x_1, x_2, x_3, \dots\dots, x_p$ be the variables and the factors (or unobserved, or latent variables) $f_1, f_2, \dots\dots, f_q$ where q < p, are the elements of the research process with sample size n.

$$x_i = \mu + \Lambda f_j + \in_i \quad (1)$$

Equation (1) is the measurement model in which $\mu\ (p \text{ X } 1), \Lambda\ (p \text{ X } q)\ and\ \in_i\ (p \text{ X } 1)$ are showing the linear relations with x_i. $\in_i$ is random measurement error which is independent of f_j such that $E(\in_i) = 0, Var(\in_i) = \Psi$ with fixed and unknowns scalars of in Ψ.

$$b_0 + B_0 f_j = \delta_{0i} \quad (2)$$

Equations of (2) are the linear structural equations, which is structural model with dimensions $b_0(d \text{ X } 1), B_0(d \text{ X q}) and\ \delta_{0i}(d \text{ X } 1)$, along fixed or unknown scalars. These linear additive structural equations are rating the factors which are 'd' in number. δ_{0i} are random errors, where $E(\delta_{0i}) = 0,\ Var(\delta_{0i}) = \Delta_0$ with fixed and unknown scalars of in Δ_0. The latent variables could be transformed as exogenous and endogenous variables using (2) which are linear in nature.
Non-linear relations could also be measured, using structural models. The endogenous variables could be analysed along with other endogenous and exogenous variables. These relations should be non-linear in the structural model.
Let $f_i = (\eta_i', \xi_i')'$ in which η_i will be the d number of endogenous variables and ξ_i will be (q - d) number of exogeneous variables. The (2) could be written as follows,

$$\eta_i = b + B\eta_i + C\xi_i + \delta_i \quad (3)$$

In which δ_i is the random equation error with $E(\delta_i) = 0, Var(\delta_i) = \Delta$ which are independent of ξ_i as well as independent of $\in_i$ in (1).
Since on both sides of (3) is having the endogenous variables η_i which is implicit function and can't be solved. So, the sufficient condition for solving equation is, pre-multiply by $(I - B)^{-1}$.
Then (3) could be written as follows,

$$\eta_i = b^* + C^*\xi_i + \delta_i^* \quad (4)$$

Where in (4) $b^* = (I - B)^{-1}b, C^* = (I - B)^{-1}C\ and\ Var(\delta_i^*) = (I - B)^{-1}\Delta(I - B)^{-1\prime}$. The equation (4) is reduced form. The additive error δ_i is independent of ξ_i in implicit form (3) which implies that δ_i^* is independent of ξ_i in reduced form (4) as equation errors.
By placing the proper limitations on $\mu, \Lambda,\ \Psi, b_0, B_0\ and\ \Delta_0$ in (1) – (2), given that p, q and d are static, it would be possible to find the values of the parameters. (2) can be written as (4) which is nothing but normal structural model. The errors in variable parameterization, in which p variables will be fixed to at least one of the q latent variables along with measurement error, is a normal limitation-imposed measurement model (1).
The generalised non-linear structural models can be written as follows,

$$x_i = \mu + \Lambda f_i + \in_i \quad (5)$$

$$H_0(f_i; \beta_0) = \delta_{0i} \quad (6)$$

These are simultaneous non-linear structural model could be described by (d X 1) vector function H_0 which is the function on known f_i and unknown parameter β_0. μ, Λ are parameters and $\in_i, \delta_{0i}$ errors with expectation zero and variances $\Psi\ and\ \Delta_0$ respectively, which are same as the linear model (1) – (2).
The endogenous and exogenous variables η_i, ξ_i could be represented as following

$$\eta_i = g(\eta_i, \xi_i; \beta) + \delta_i \quad (7)$$

(7) is implicit which could be reducible to

$$\eta_i = h(\xi_i, \delta_i; \beta^*) \quad (8)$$

In (8), h (d X 1) is a vector function β^* unknown parameter, and δ_i is error, but independent of ξ_i. So, the reduced form is nonlinear structural model. In the similar way subclasses of nonlinear structural models could be derived (Melanie & et.al, 2007).
All these relations have been executed in JASP (Jeffreys's Amazing Statistical Program) environment. The results will be discussed in the next part of the paper.

4 Results and Discussion

4.1 Discussion for the first research question

The pattern of the clusters in Principal compound analysis is informing about learners' sensitivity towards their mathematics-learning environments. The first compound is containing self-learning effort (SML, LPEL), second is the engagement with mathematics-subject (LEM), third is the formal learning-environment (LPCL) and forth is their attitude towards Mathematics learning (LAM). The formation PCs and its order have been motivated to do the further investigation about the learning environments, which could be observed form Table 1.

Table 1

Principal Compounds	Observed Variables	Uniqueness of Variables' for PCs
PC 1	SML1	0.226
	SML2	0.229
	SML3	0.241
	SML4	0.267
	SML5	0.263
	LPEL4	0.319
	LPEL2	0.277
	LPEL3	0.313
	LPEL5	0.336
PC 2	LEM2	0.117
	LEM4	0.188
	LEM3	0.133
	LEM5	0.199
	LEM1	0.163
PC 3	LPCL3	0.185
	LPCL2	0.165
	LPCL4	0.220
	LPCL5	0.250
	LPCL1	0.254
PC 4	LAM3	0.181
	LAM2	0.158
	LAM5	0.200
	LAM1	0.229
	LAM4	0.270
	LPEL1	0.315

Among the PCA clusters, first three are showing the learners' perception about their learning environments and engagement with mathematics. In the next part, the second and third research questions' discussions will be carried out, which will be indicating about necessity and significance of dynamic learning environment.

4.2 Discussion for the second research question

The path analysis of derived-structural equation model (Figure 2) of the following factors LAM, LEM, LF, SML, LPEL and LPCL are significant enough to modify the tradition way teaching-learning process. Learners' attitude and engagement with classroom mathematics-learning are positive loads with 0.21 and0.19 respectively. This is clear indication of their interest towards formal way of learning the subject. As per theoretical measurements among the factors from LF to SML, SML to LPEL and LPEL to LPCL are 0.42, 0.75 and 0.37 respectively. The other way loads from LF to LPEL and LPEL to LPCL are 0.05 and 0.37 respectively. There is an evident proof for the importance of SML (informal factor) towards the formal learning LPCL, as per the learners' opinion.

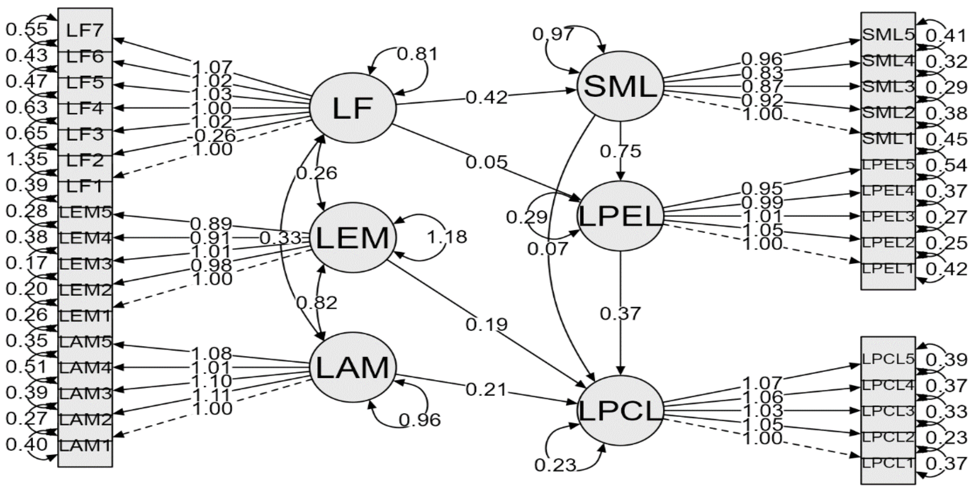

Figure 2: SEM for Factor Analysis without Performance factor

Effective learning process could be executed among the educational stake-holders by introducing the social media- metaverse in the process of acquiring knowledge (Mitra, 2023). With proper time management of 80-20 or 70-30 percentage ratio could be accommodated in the instructional planning. Means 80 or 70 percent for formal instructional process, 20 or 30 for learning with help of metaverse as digital twins (or Avatars). These digital twins could be the educators and learners. During the practice sessions bight learners can help the slow learners or project presentations in group could be performed, which could be value-added part in the formal virtual learning process.

4.3 Discussion for the third research question

The mediation effects between the factors in the first two paths (LF to SML, SML to LPEL and LPEL to LPCL, LF to SML and SML to LPCL) are showing the significant importance of SML in mathematical-skill acquiring process which could be measured indirectly. Formal learning environment should more effective when the informal learning aspect is present in the process of learning.

4.4 Discussion for the third research question

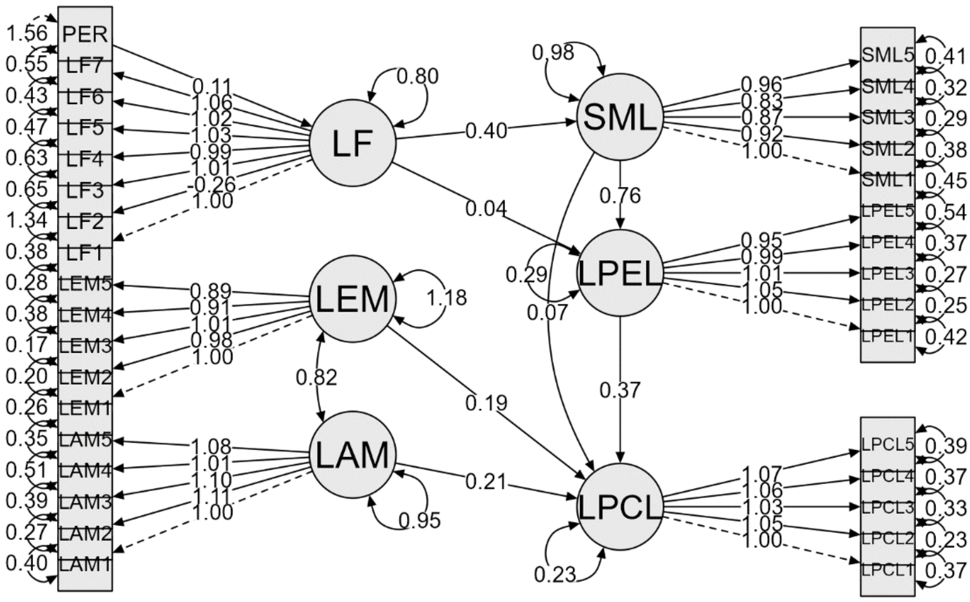

Figure 3: SEM for Factor Analysis with Performance factor

Inclusion of learners' performance as an endogenous variable in SEM (Figure 3), also supports the above-mentioned theatrical results. Path analysis shows almost same logical results. The educational stake-holders could reform the educational process by integrating strongly social media in the formal education which will lead the skilful society. As per the announcement by Mark Zuckerberg, 2021 the metaverse is going to be the next updated and iterated version of internet, similar way by changing educational stake-holders as digital twins is also possible after some years.

5. Conclusion

The change or advancement of any system (or process) is quite obvious part in every aspect of society. Existing formal way of getting trained, for acquiring special skills could be achieved, with proper logical approach. Such approach is derived from Mathematical thinking. Performance in mathematics is the basic need to acquire such thinking. Enhancement in the higher education learners' performance in mathematics subject is possible by adapting modified way of teaching-learning process. The learning environments could be iterated as per the learners' logical and actual requirements. Integration of group learning, project-based learning, collaborative learning and self-learning along with social media learning and creating the new eco-friendly and virtual intractable learning environments can improve the learning experience. Integration of Holograms along with virtual boards, as a mobile application could be the game-changer aspect for upgrading the learning environments.

Abbreviations

ANN - Artificial Neural Network
CFA - Confirmatory Factor Analysis
DNN - Deep Neural Network
EFA - Exploratory Factor Analysis
HEL - Higher Education Learners
JASP - Jeffreys's Amazing Statistical Program
LAM - Learners' Attitude towards Mathematics-Learning
LEM - Learners' Engagement with Mathematics-Learning
LF - Learning Factors
LPCL - Learners' Perception about Classroom Learning
LPEL - Learners' Perception about Extra Learning
ML - Machine Learning
PCA - Principal Compound Analysis
PCs - Principal Compounds
SEM - Structural Equation Modelling
SML - Social Media Learning

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