An Explorative Structural Equation Modeling of Grades for Engineering & Technology Educational Research

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Abstract

Structural equation modeling (SEM) has been used to probe the aspects that concern causative hypotheses/elements contained in engineering and technology educational research datasets; and to study the potential causal relationships. The grades in remedial courses (reading, writing and high school math), college math, first physics course and graduation GPA are used as indicators used to define latent variables "English Aptitude" and "Math Aptitude" in SEM. The dataset consists of 167 graduates over ten years in a community college. An initial confirmatory factor analysis model suggests that "English Aptitude" and "Math Aptitude "has a correlation of 17%. A follow up SEM suggests that "English Aptitude" has a 32% loading onto the 'Math Aptitude", which has a 97% manifestation on the graduation GPA. The "English Aptitude" has a 53% manifestation on the remedial zero credit high school math course grades. The SEM results give a quantitative assessment for the remedial program effect on overall graduation GPA in this explorative study. The SEM of evaluative scores/grades in an introductory physics courses (N = 80) is illustrated with a representative model that shows a latent variable "Hands-on Aptitude" having manifestations in kinematics and laboratory grades, and has a 100% loading on another latent variable "Concept Theory Aptitude". Extension to other pre-engineering course grades is discussed briefly.

Keywords: structural equation model, LISREL software, educational research

Introduction

Structural equation models (SEM) have been used to probe the aspects that concern causative hypotheses/elements contained in engineering and technology educational research datasets [1]. The causative hypotheses/elements would convey causal assumptions, but not necessarily a model that would generate validated causal conclusions. Structural equation model analysis is an improvement over correlation relationship analysis and points toward potential causal relationship. The potential causal relationships of remedial courses to graduation, laboratory learning to lecture learning, etc are important questions in pedagogy. A causative approach would start with a candidate model that could explain the "dependent" variable, together with the underlying latent variables. Causative research is usually more extensive than correlative research, with a deeper analysis into theory, hypothesis, and testing. A causative approach would extend a correlation model into areas such as model-testing with the use of SEM across time in a longitudinal dataset such as grades in sequential courses. LISREL (LInear Structural RELations) is a popular software package used by researchers for structural equation modeling [2]. The methodology has been most popular in the field of psychology and education; but very few works had been conducted in engineering and technology pedagogy. Recently a SEM study was conducted by psychologists on the learning of physics using incentive offering survey data with 51% participation rate [3]. This explorative study focuses on the grades in an engineering technology program in a community college (N = 167). All of the grades from three remedial courses, college math course and an introductory physics course are used as data for the indicators (or manifest variables). A model usually postulates a pattern of relationships among a set of indicators (manifest variables) and latent variables. The model would then be used to account for observed variation in scores/grades on the manifest variables, and would express the manifest variables as functions of other manifest and latent variables. The “English Aptitude” and “Math Aptitude” would be treated as latent variables.

Models

A confirmatory factor model could be expressed as the following

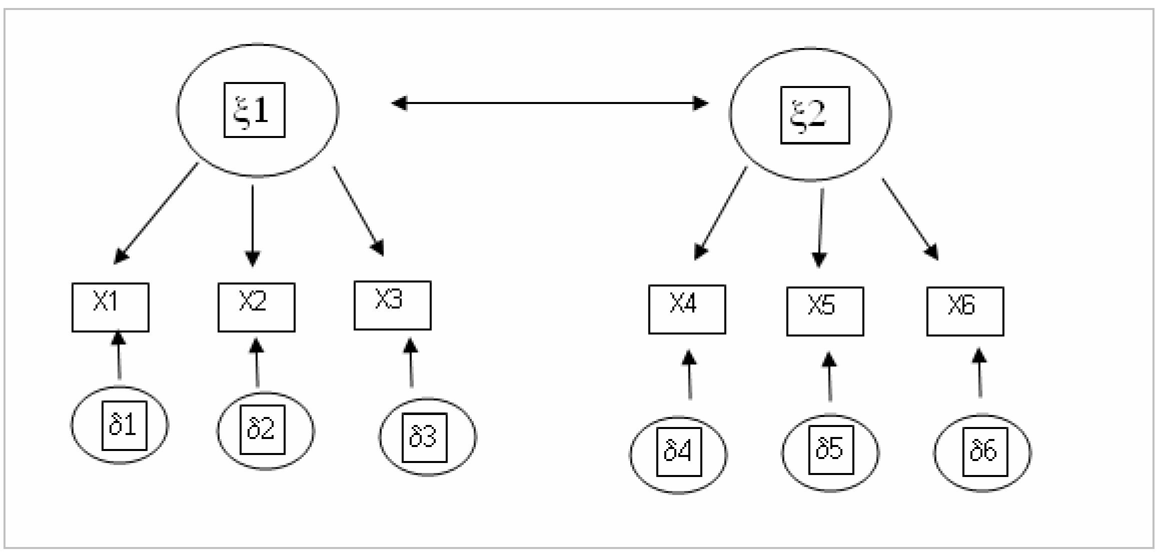

Figure 1: Path Diagram of a confirmatory factor model as represented by Equation 1.

$x = \Lambda \xi + \delta$ (Equation 1)

in which x is the vector of observed variables, Λ (lambda) is the matrix of loadings connecting the ξ_i (latent variables as factors) to the x_i, (observed or manifested variables or indicators)

ξ is the vector of common factors, and δ is the vector of unique factors. It is usually an assumption that the error terms have a mean of zero, $E(\delta) = 0$, and that the common and unique factors are uncorrelated, $E(\xi\ \delta'') = 0$. Equation 1 can be rewritten as

$x_1 = \lambda_{11} \xi_1 + \delta_1$ $x_2 = \lambda_{21} \xi_1 + \delta_2$ $x_3 = \lambda_{31} \xi_1 + \delta_3$

$x_4 = \lambda_{42} \xi_2 + \delta_4$ $x_5 = \lambda_{52} \xi_2 + \delta_5$ $x_6 = \lambda_{62} \xi_2 + \delta_6$

Our model is displayed in Figure 2. MA-10, READ, WRITE are remedial courses with no college credit. MA114 is the pre-requisite for PH201/30, an introductory physics algebra based course for engineering technology students in the general education core. The correlation of 17% of the latent variables suggests a SEM approach. The SEM result is displayed in Figure 3. The results suggest that "English Aptitude" has a 32% loading onto the 'Math Aptitude", which has a 97% manifestation on the graduation GPA. The "English Aptitude" has a 53% manifestation on the zero credit remedial high school math course grades. The SEM results give a quantitative assessment for the remedial program effect on overall graduation GPA in this explorative study

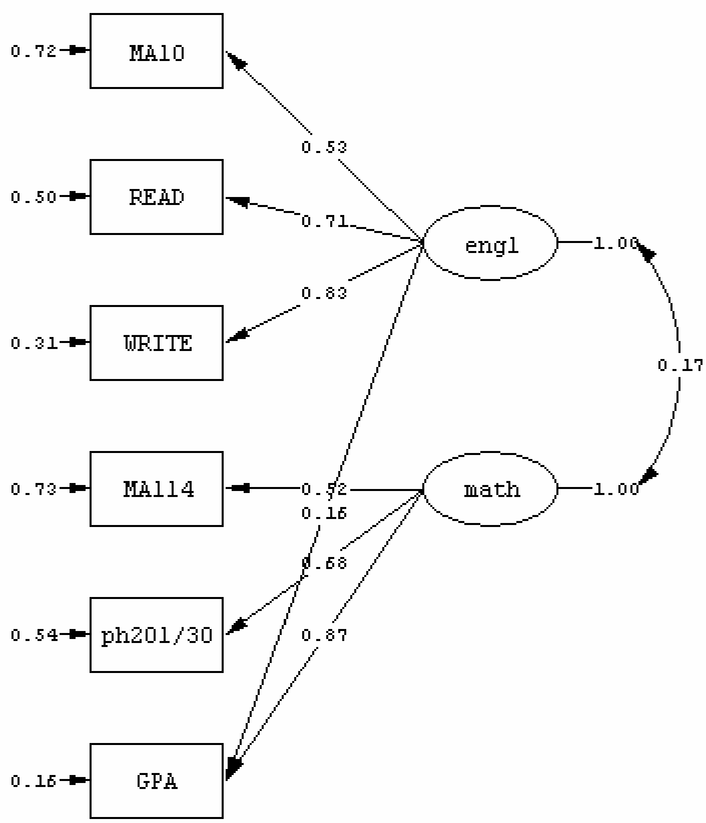

Figure 2: A confirmatory factor model with numeric results

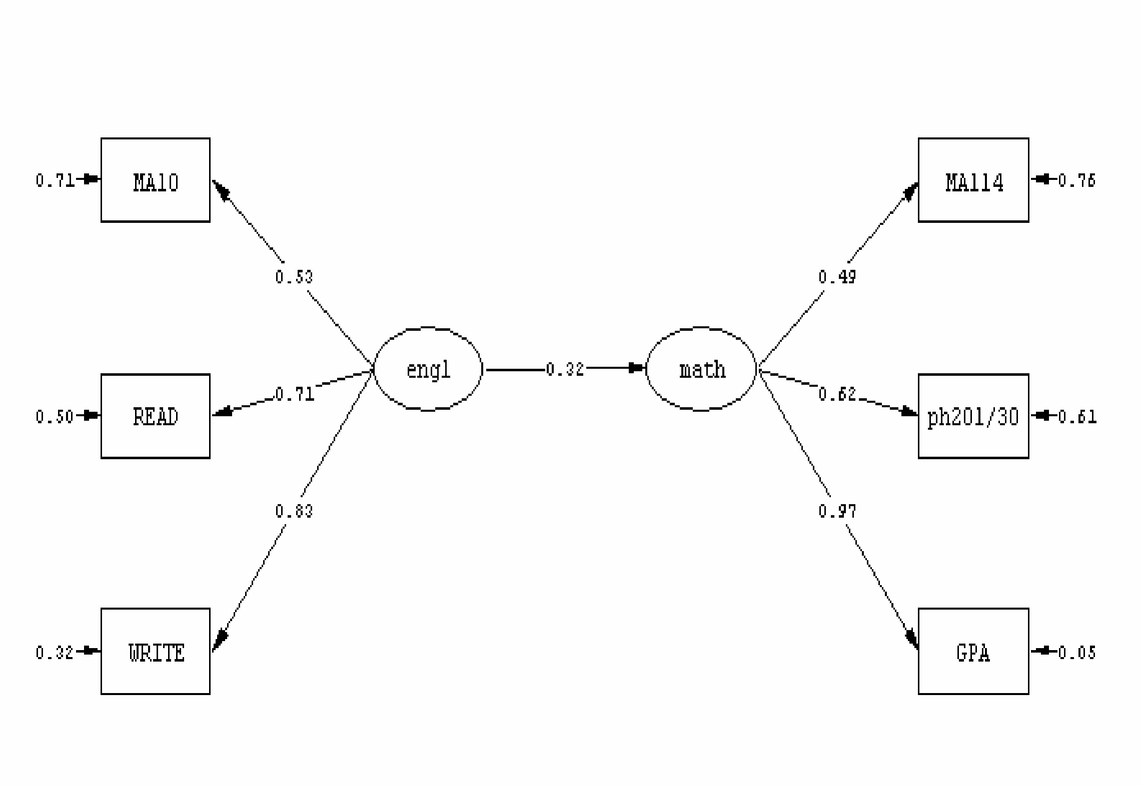

Figure 3: An alternative structural equation model of the same dataset as in Figure 2.

A recent SEM educational psychology study used gains from pre- to post-administration of the Force Concept Inventory (FCI) as indicator for concept change in physics and other data for indicators such as "need for cognition" [4]. The above SEM analysis without survey-based data was applied to simulated scores/grades within an introductory physics course. The simulation was based on the statistics of the sample scores/grades and would serve as a guideline for the studied data stability. The SEM of evaluative scores-grades in an introductory physics courses (N = 80) is illustrated with a representative model that shows a latent variable "Hands-on Aptitude" having manifestations in kinematics and laboratory grades, and has a 100% loading on another latent variable "Concept Theory Aptitude". The indicator "kinemat" consists of the scores on the first test on kinematics up to projectile motion. The indicator "lab" consists of the scores on the 14-week of labs. The indicator "newton" consists of scores on the second test on Newton's Laws. The indicator "conserv" consists of scores on the third test on momentum conservation and energy conservation. The indicator "lect_fin" consists of scores of the final exam that covers kinematics all the way to rotation in a standard first physics course. The SEM results would suggest that students who succeeded in the program would use "Hands-on Aptitude" to understand kinematics, which is consistent with daily awareness of projectile motion in ball games, motion in cars, etc. The actual data yielded slightly different numerical results with the same interpretations.

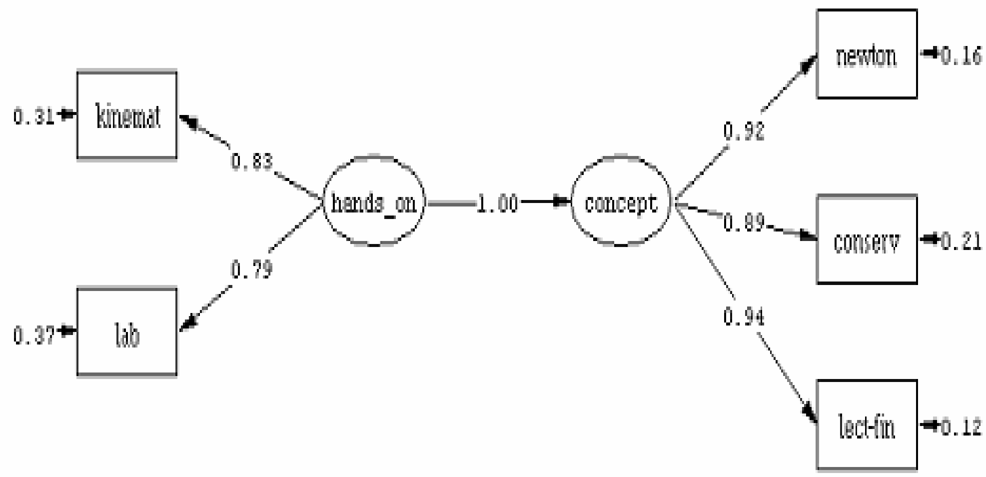

Figure 4: A SEM of scores/grades in an introductory physics course. The presented numerical results were based on simulated data. The actual data yielded slightly different numerical results (within 5%) with the same interpretations.

Discussion

The acceptance and consistency within a SEM statistical calculation does not prove the causal relationships in a model. A causal conclusion does not depend on the SEM calculation, but rather on the design and/or prior theory such as remedial courses are pre-requisites. The SEM models provide quantitative assessment of the causative hypotheses/elements in a sequence of courses as well as in a sequence of tests within a course. Other failed non-converging models are not presented. For example, MA-10 indicator being modeled as part of "Math Aptitude" in Figure 3 would fail; thus suggesting that successful student would be able to use "English Aptitude" to handle the word-problems in MA-10. The indicator "kinemat" when modeled as part of "concept-theory aptitude" in Figure 4 would fail. The so called failures actually could reveal misconceptions and offer deeper insight on the teaching-learning process that builds on the previous processes. Extension to other pre-engineering courses could proceed in a similar fashion for a more comprehensive program assessment. For example, the connection of college English to lab report grades could be assessed.

Conclusions

This explorative project shows that structural equation model is capable of providing quantitative information on the causative hypotheses/elements such as pre-requisites in a sequence of courses. The LISREL software is fairly easy to implement and it is hoped that the presented results would popularize the application of SEM in engineering and technology program pedagogy.

Acknowledgements

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