

Structural Equation Modeling in Educational Research: A Case-study for PhD Training

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Abstract: The article deals with the problem of using structural equation modelling (SEM) methodology in educational research. It allows the researcher to build multidimensional models of the phenomena and processes that are being studied. The SEM methodology is based on many well-known methods such as correlation, regression, factor analysis, variance analysis and covariance analysis. The methodology is mainly based on deductive logic, involves the preliminary construction of a structural model of relationships between variables in order to further check for consistency with the experimental data. The article summarizes the use of various SEM software in the training of doctors of philosophy of the world’s leading universities and provides an example of using the SEM methodology in educational research for PhD student training. An important point in preparing specialists for using SEM is to select or obtain the necessary data sets that are representative and valid. During the research the Ukrainian teacher’s self-efficacy model with SEM methodology was checked, and the obtained results were compared with the research data of the worldwide teacher’s survey – The Teaching and Learning International Survey (TALIS). The lower self-efficacy of Ukrainian teachers, especially in the student engagement block, was showed.

1 INTRODUCTION

1.1 Setting of a Problem


In recent years, many PhD programs were organized in Ukraine. Qualitative scientific research is impossible without a systematic description of the studied phenomena; multidimensionality of the investigated phenomena requires the use of multidimensional analysis methods that are capable to identify causal relationships, latent factors, etc. A promising area in the field of multidimensional applied analysis is the structural modeling or structural equation modeling, which is becoming an increasingly popular tool for researchers in the field of education, psychology and social sciences (Kline, 2015; Khine, 2013; Mitina, 2008; Nasledov, 2013; Chorny, 2011).


In our article (Panchenko et al., 2021) the three focuses of the research component of doctoral program are proposed. The first focus relates to reproducible

research principle. The second focus is related to the use of multivariate models of phenomena’s study and SEM methodology. The SEM methodology is mostly based on deductive logic, involves the preliminary construction of a structural model of the relationships between the variables in order to further check for consistency with the experimental data. The third focus combines qualitative and quantitative methods and the use of triangulation (data triangulation, investigation triangulation, theory triangulation etc.). The content of selected courses for doctorate students is proposed: Reproducible Research and Multivariate Methods in Scientific Research courses.

In this article, we focus on the SEM methodology; we consider it very important to train future doctors of philosophy to use it in the educational research.

The popularity of the SEM methodology is evidenced by the experiment we conducted. At the request of “structural equation modeling” to search books on Amazon.com (as of March 16, 2013), we obtained 59 items, the graph of which is clearly shown in figure 1. In the center of the graph (figure 1, on

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the left), where 5 subgraphs can be observed, there is the third edition of the bestseller, *Principles and Practice of Modeling by Structural Equations* by Kline (Kline, 2015). The companion site of this publication provides methodological support and offers download syntax, data and source files for all sample books for execution in three environments EQS, LISREL and Mplus, and a comparison of simulation results. A similar experiment, conducted on March 28, 2019 (figure 1, on the right), shows interest growth in structural modeling; we have 157 items. Interestingly, the fourth edition of the same bestseller has the biggest rating there.



Figure 1: Books on “ structural equation modeling”, Amazon.com, year 2013 versus 2019.

While solving the scientific problem of training PhDs to use the SEM methodology, the following main results were obtained in past author works: the content of the simulation training by the structural equations of specialists in the field of education is revealed; the dynamics of software simulation by structural equations is analyzed; the necessity of including these means in the courses for students and graduates of higher educational institutions of Ukraine that specialize in the field of education and social sciences is substantiated (Panchenko, 2013).

The syllabuses of PhD SEM courses of leading universities are analyzed (Higher School of Economics, St. Petersburg; University of Amsterdam; University of Vaasa, Finland; University of Mannheim; Iowa State University; Brown University; University of Leuven; School of Education University of Pittsburgh; Oslo University etc).

An analysis of the best PhD programs in sociology according to the Princeton Review’s “Gourman Report of Graduate Programs” (Plous, 2021) showed that they must have courses on structural equation modelling. In table 1, we summarize the use of various SEM software in the training of doctors of philosophy of the world’s leading universities.

Analysis of syllabuses (table 1) showed that in general the courses are organized in the format of seminars. The main activity is created at the intersection of lectures, group discussions, software application and interpretation of results. Teaching materials

are available through the Blackboard or Moodle learning management system. The number of course credits ranges from 1 to 6 with 1–3 credits for introductory courses, and 4–6 credits for advanced. Courses are offered as part of the training of doctors of philosophy in the field of pedagogy, psychology, sociology, statistics, information systems and business, public health, sports, etc. Both proprietary and free software is used. In most courses, one software tool is acting as the main tool, and another one as an additional. But there are courses in which several software tools are widely used.

Here is an example of evaluating the work of students in the course (www.soc.iastate.edu, 2021). Homework with the use statistical software: 8%; critical review of articles on the topic (4 reviews of 4–5 pages): 30%; statistical analysis (4 reports of 12–15 pages): 62%. For a critical review, the parameters of its evaluation are given: for example, to explain the basic model that the author evaluates (20% of the mark); discussion of critical mistakes made by the author (40%); an explanation of how the casual effect (40%) can be correctly estimated. Some programs offer an exam and a final project during the course as their own mini-study on the use of SEM.

The objectives of the SEM courses are defined as follows: using structural equation modeling methodology to study the problems of social and behavioral science, understanding the strengths and flaws of the method and its limitations, teaching methods of assessment, identification models, testing their validity, interpretation, critical evaluation of scientific publications on this subject, using statistical software to perform structural equation modeling analysis, preparation of research reports in accordance with the standards of research (Panchenko and Razorova, 2016).

In preparing specialists for using SEM an important point is to select or obtain the necessary data sets that are representative and valid. We offer our students the survey data from Ukrainian teachers (Shchudlo et al., 2018; TALIS, 2017; Questionnaires, 2017).

On August 31, 2017, the Ukrainian Association of Educational Researchers completed the All-Ukrainian monitoring “Teaching and Learning Survey on Principals and Teachers of Secondary Education Institutions” (based on the TALIS methodology (OECD, 2018)). The study was conducted within the framework of the project “Teacher” and “Education Reform: Quality Assessment in an International Context”, which is implemented by the All-Ukrainian Foundation “Step by Step” with the support of the Ministry of Education and Science of Ukraine (Shchudlo et al., 2018). The study was attended by

Table 1: Software in SEM courses.

Course name	Software						
	AMOS SPSS	EQS	Mplus	Lisrel	Open Mx	SAS	R
"Modern Social Analysis", HSE, St. Petersburg			+				
"Structural equation modelling in educational research", University of Amsterdam			+	+	+		
"Latent Structural Equation Modeling", University of Vaasa, Finland	+		+	+		+	+
SEM1, University of Oregon	+		+				
"Structural equation modelling using LISREL and EQS" (SEM PhD workshop)		+		+			
"Structural Equation Modeling in the IS Discipline", University of Mannheim	smart PLS						
"Structural equation models for social and behavioral research", Iowa State University							
"Structural Equation Models in the Social Sciences", University of Brown				+			
"Causal analysis and structural equation modeling"			+ Stata				
"Structural Equations", University of Leuven, PhD in Statistics				+			
"Structural Equation Modeling", School of Education University of Pittsburgh			+		+		
"Structural equation modeling: Longitudinal models and multi-group models", University of Oslo			+				
"Building and Testing Structural Equation Models In the Social Sciences", University of Michigan	+	+		+			
"An introduction to structural equation modelling", Doctoral college of Ulster University							
"PhD-M: Structural Equations Modeling", University of Vienna				+			
PSY9140 -- "Structural Equation Modelling", Oslo university			+				+
PSY8006 -- "Introduction to Structural Equation Modeling (with MPlus)", Norwegian university of science and technology			+				
Introduction to Structural Equation Modeling (Sem), PhD School of Copenhagen Business School			+				
Structural Equation Modeling, HSE, Russia							+

3,600 teachers and 201 school principals from 201 schools, representing all regions of Ukraine. The results of the study, according to the OECD policy, are open and accessible.

The purpose of our article is to show the ways to apply the SEM methodology in educational research for PhD students. In our case-study, we will, based on the survey data of Ukrainian teachers, check the

model of teacher's self-efficacy with SEM methodology, and compare obtained results with the research data of the worldwide teacher's survey – TALIS.

1.2 Related Works

The methodology of structural modeling has received wide recognition in the global community. The study

of the basics of structural modeling has become a component of the training of researchers specializing in social sciences (Panchenko and Razorova, 2016). In Russia, the ideas of structural modeling in relation to psychology are reflected in (Mitina, 2008; Nasledov, 2013). The use of SEM with an emphasis on economic research has been studied by Chorny (Chorny, 2011). Unfortunately, in Ukraine, structural modeling is not sufficiently used in educational and social studies in general, and in the training of researchers at universities, in particular.

The aspects of the application of the SEM methodology to educational data (TALIS, 2013) are devoted to the following research. A structural equation model of determinants of the perceived impact of teachers' professional development (the Abu Dhabi application) is reviewed by Badri et al. (Badri et al., 2017). How school context and teacher's characteristics predict distributed leadership is presented by Liu et al. (Liu et al., 2018). The invariance of teachers' sense of self-efficacy measured across countries is reviewed by Scherer et al. (Scherer et al., 2016).

2 RESULTS OF THE STUDY

TALIS (Teaching and Learning International Survey) is one of the most prestigious international comparative education projects. The project is dedicated to studying the environment and work conditions of school teachers. It has been implemented since 2008 by a research consortium under the Organization for Economic Cooperation and Development (OECD). 24 OECD countries and partner countries participated in the first wave of TALIS study in 2008, 34 – in the second wave in 2013, and 44 countries plan to participate in 2018 (Shchudlo et al., 2018; OECD, 2018).

All-Ukrainian monitoring survey of teaching and learning among school principals and teachers of general educational institutions (according to the methodology All-Ukrainian research on TALIS methodology) is an example of use of international instruments for studying national educational space and identifying the place of the Ukrainian teacher community in the international community educational context. The purpose of the research is to identify and analyze socio-demographic and professional characteristics of Ukrainian teachers and academic staff and the environment of schools on the basis of reliable comparable metrics (Shchudlo et al., 2018).

3600 teachers of 5–9 grades of secondary schools (level ISCED 2) and 201 school principals from 201 schools participated in the survey in 2017. Error of simple random sampling is 1.6%, the school sam-

ple selection error takes into account design effect is 2.3%.

From the Ukrainian teacher's survey file (TALIS, 2017) we selected 3477 lines without missing values for 12 variables that represented the teacher's self-efficacy (table 2).

Bandura (Bandura, 1982) defines self-efficacy as a personal judgment of "how well one can execute courses of action required to deal with prospective situations". He names four sources of efficacy beliefs: 1) mastery experiences; 2) vicarious experiences; 3) verbal persuasion; 4) emotional and physiological states.

Professional teacher's self-efficacy, in general, is the perception of a person's own ability to mobilize motivation, cognitive resources and behavioral activity that are needed to control the situation in order to achieve the intended purpose (Bandura, 1982; Kremeshna, 2010; Krasnoryadtseva et al., 2014).

TALIS model for teacher consists of three components of self-efficacy: self-efficacy in classroom management; self-efficacy in instruction; self-efficacy in student engagement.

We will conduct a factor analysis for these data. The obtained values of Kaiser-Meyer-Olkin (0.902) and Bartlett's Test of Sphericity (13308, $p < 0.001$) indicate that factor analysis is a suitable method for these data. The scree plot below shows three factors (figure 2).

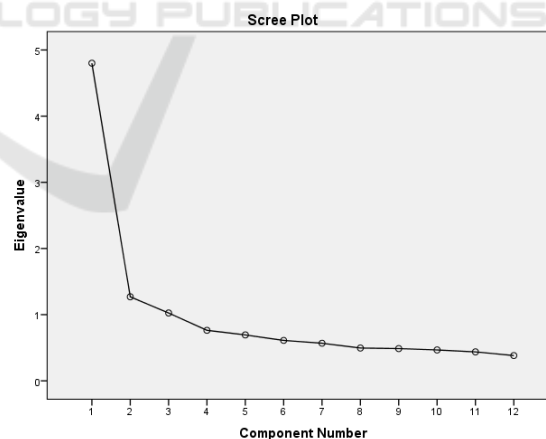


Figure 2: Scree plot: a line plot of the eigenvalues of factors.

Let us consider the rotated component matrix (table 3). It demonstrates that the first factor, loading high factor weight of the attributes, is related to the class management, the second one is related to the student's engagement, and the third one to the instruction.

You can also observe that the variable "Craft good

Table 2: Variables of teacher’s self-efficacy.

Variable name	Content
TT2G34A	Get students to believe they can do well in school work
TT2G34B	Help my students value learning
TT2G34C	Craft good questions for my students
TT2G34D	Control disruptive behavior in the classroom
TT2G34E	Motivate students who show low interest in school work
TT2G34F	Make my expectations about student behavior clear
TT2G34G	Help students think critically
TT2G34H	Use a variety of assessment strategies
TT2G34I	Provide an alternative explanation, for example, when students are confused
TT2G34J	Implement alternative instructional strategies in my classroom
TT2G34K	Get students to follow classroom rules
TT2G34L	Calm down a student who is disruptive or noisy

Table 3: Rotated component matrix.

	Factor 1: Class man- agement	Factor 2: Student En- gagement	Factor 3: Instruction
Control disruptive behavior in the classroom	.795		
Calm a student who is disruptive or noisy	.773		
Get students to follow classroom rules	.765		
Make my expectations about student behavior clear	.596		
Help my students value learning		.816	
Get students to believe they can do well in school work		.764	
Motivate students who show low interest in school work		.644	
Help students think critically		.448	
Craft good questions for my students		.443	
Provide an alternative explanation, for example, when students are confused			.785
Implement alternative instructional strategies in my class- room			.736
Use a variety of assessment strategies			.730

questions for my students” is more related to the factor “Student engagement” than the factor “Instruction”. As you see, three factors explain 59.1% of variability (table 4).

Table 4: Total variance explained.

Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1	2.571	21.425	21.425
2	2.313	19.274	40.698
3	2.211	18.429	59.127

Scientists identify next five steps in SEM application (Kline, 2015; Nasledov, 2013).

- 1) model formation. The model depicts the graphical views of the researcher about the structure of the variable and latent constructs of ties. At the same time, they decide which parameters should be fixed, and which should be left free.

- 2) model identification
- 3) model evaluation
- 4) checking the consistency of the model
- 5) model correction by adding new links and eliminating insignificant links.

Let us build a model of confirmatory factor analysis with AMOS SPSS (figure 3).

You can see the resulting teacher’s self-efficacy model in the figure 4.

We got the following results. Number of distinct sample moments: 78; number of distinct parameters to be estimated: 27; degrees of freedom: 78–27=51. Criteria for coherence RMSEA 0.07 < 0.08, that is, the model is consistent with the data.

Using the data (Shchudlo et al., 2018), we clearly compared the indicators of self-efficacy of teachers in Ukraine and in the world (table 5, figure 5). The graph shows that self-efficacy of Ukrainian teachers

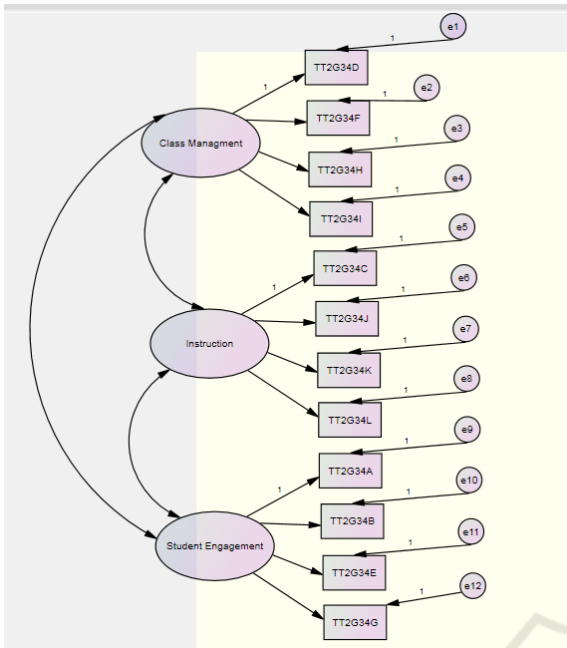


Figure 3: Initial teacher's self-efficacy model in AMOS SPSS.

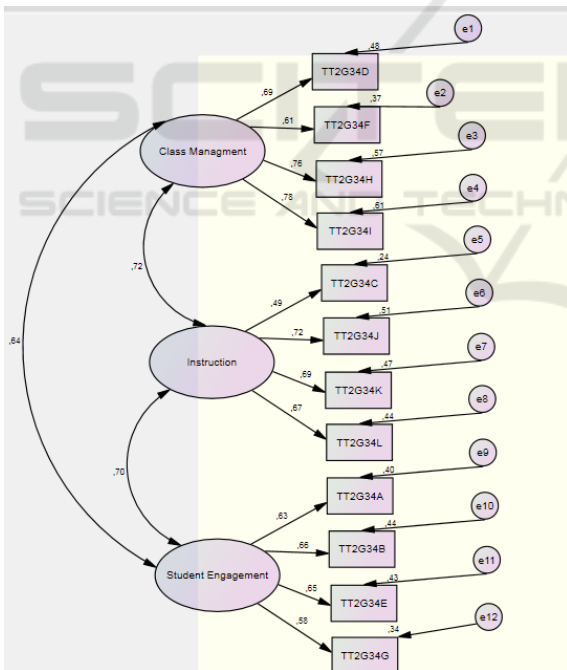


Figure 4: Resulting teacher's self-efficacy model in AMOS SPSS.

is lower, especially in the student engagement block (variable "Get students to believe they can do well in school work" – difference was 26.4%, "Help my students value learning" – 26%, "Motivate students who show low interest in school work" – 19.4 %).

As a continuation of the research, PhD students

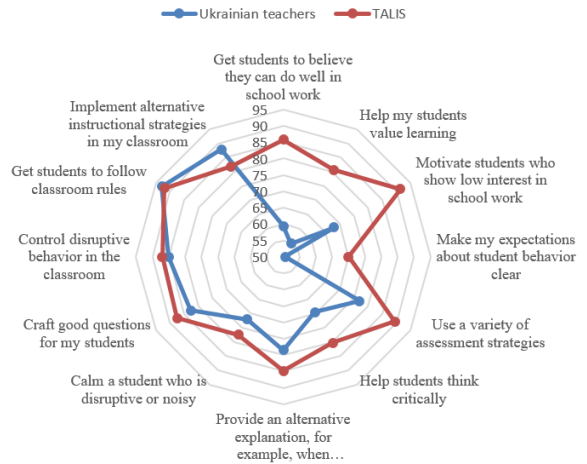


Figure 5: Comparison of teachers' self-efficacy in Ukraine and in the world.

can be invited to analyze the results of a recently published survey TALIS 2018. TALIS 2018 (Plous, 2021) identifies a number of factors that are related to teacher self-efficacy:

1. Teacher characteristics: years of experience as a teacher
2. Index of classroom disciplinary climate
3. Took part in any induction activities at current school
4. Induction activities at current school included team teaching with experienced teachers
5. Professional development activities in the 12 months prior to the survey did have a positive impact on teaching practice
6. Index of workplace well-being and stress
7. Fixed-term contract: less than or one school year
8. Index of professional collaboration
9. Index of target class autonomy

This relationship does not apply to all countries (table 6).

An interesting task for PhD students is to build the SEM model taking into account factors of teacher's self-efficacy according TALIS 2018.

3 CONCLUSIONS AND PERSPECTIVES OF FURTHER RESEARCH

Measurements that are used in modern educational research are becoming more and more complex. The author's vision of the research component of training

Table 5: Indicators of self-efficacy of teachers in Ukraine and in the world (%).

Variables	Ukrainian teachers	TALIS	Difference
A. Get students to believe they can do well in school work	59.4	85.8	26.4
B. Help my students value learning	54.7	80.7	26
C. Craft good questions for my students	82.6	87.4	4.8
D. Control disruptive behavior in the classroom	85	87	2
E. Motivate students who show low interest in school work	50.6	70	19.4
F. Make my expectations about student behavior clear	68	91.3	23.3
G. Help students think critically	69.5	80.3	10.8
H. Use a variety of assessment strategies	77	89.4	12.4
I. Provide an alternative explanation. for example. when students are confused	78.5	84.8	6.3
J. Implement alternative instructional strategies in my classroom	87.8	81.9	-5.9
K. Get students to follow classroom rules	92.9	92	-0.9
L. Calm a student who is disruptive or noisy	72	77.4	5.4

Table 6: Factor of self-efficacy of teachers in TALIS 2018 and number of countries and percentage of countries with positive and negative relation (%).

Factor	N+	%+	N-	%-
Teacher characteristics: years of experience as a teacher	29	60.4	0	0
Index of classroom disciplinary climate	0	0	45	93.8
Took part in any induction activities at current school	25	52.1	0	0
Induction activities at current school included team teaching with experienced teachers	35	72.9	0	0
Professional development activities in the 12 months prior to the survey did have a positive impact on teaching practice	33	68.8	0	0
Index of workplace well-being and stress	0	0.0	42	87.5
Fixed-term contract: less than or one school year	0	0.0	15	31.3
Index of professional collaboration	46	95.8	0	0
Index of target class autonomy	47	97.9	0	0

PhD students focuses on three areas: reproducible research; multivariate analysis and SEM methodology; triangulation (Panchenko et al., 2021). SEM methodology helps researcher determine the effectiveness of educational innovations in different educational contexts, as well as model and study phenomena in their interrelations; understand the influence of latent factors, develop systemic and critical thinking.

An important point in training specialists to use SEM is to select or obtain the necessary data sets that are representative and valid. For example, we offer our students such data: All-Ukrainian survey data from Ukrainian teachers. The main criteria for choosing it are: 1) an array of data is freely accessible, 2) it is large (contains 3600 lines), 3) it is accompanied by supporting documentation, 4) the array and documents have Ukrainian and English versions, 5) the array variables are simple and understandable, 6) it is possible to conduct comparative studies with the data of the International Talis Teacher's Survey.

During the case study the teacher's self-efficacy model using SEM methodology were checked, the

obtained results were compared with the TALIS survey data (2013). The research demonstrated that self-efficacy of Ukrainian teachers, especially in the student engagement block, was lower.

Further development of work in this direction is the creation of teaching and methodological support for modeling by structural equations in the form of a computer workshop in the AMOS and R environments for the training of researchers in the field of pedagogy and social sciences and a proposal to include SEM in higher education research.

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