Factors Affecting Teachers' Integration of Visualization Technology in Geometry: PLS-SEM Analysis

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Abstract: - Visualization is identified as a crucial element that affects students' performance in Geometry. Technology plays an important role to assist weak students in visualizing concepts in Geometry. Teachers need proper planning in teaching to help their students in understanding the concepts. This study used partial least squares-structural equation modelling (PLS-SEM) to test the hypotheses to verify the effects of variables on teachers' intention of integrating visualization technology in teaching geometry. The model consists of four constructs: teaching strategy, teaching activity, selection of media, tools and teaching aids, and assessment. The research instrument consisted of 30 survey questions for four main constructs: teaching strategy, teaching activity, selection of media, tools, and teaching aids and assessment. The questionnaires were distributed to 180 teachers who teach Mathematics in secondary schools. The study used a PLS-SEM modeling tool to analyze data for reliability and validity. Results show that teaching strategy, teaching activity, selection of media, tools and teaching aids, and assessment significantly influence the integration of visualization technology in Geometry. This finding is a reference for policymakers and implementers to improve the quality of teaching and learning in Geometry for secondary schools.

Key-Words: - visualization technology, secondary mathematic teachers, geometry, visual-spatial skill, level of geometrical thinking, PLS-SEM

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1 Introduction

Geometry is one of the fields in Mathematics that requires students to construct knowledge based on visualizing shapes and diagrams, [1]. Visualization plays a vital role to help students master the concepts to solve problems correctly. It is acknowledged to be the reason for the student's poor performance in Geometry, [2]. Geometry is important to students because it is related to their life and future, [3]. Therefore, the Ministry of Education (MOE) highlighted the students' weakness in Geometry as one of the issues in education that needs an immediate solution, [4]. In addition, a report from Trend in Mathematics and Science Studies (TIMSS) 1999-2019 showed that Malaysian students' scores in Geometry were below the average international level, [4]. TIMSS is an international assessment for Mathematics and Science, which is conducted every four years for students who are 14 years old, [5]. Hence, teachers need to find ways to motivate students in learning Geometry.

Previous studies had shown that technology provided tools for students to visualize concepts, [6], [7]. The teachers use digital and non-digital technology in their teaching, [8]. In Malaysia's educational system, teachers are encouraged to integrate digital technology such as Information, Communication, and Technology (ICT) in teaching, [9]. On the other hand, teachers can also use non-digital technology such as graphic calculators and scientific calculators, [10]. In [11], the author suggested visualization technology (VT) as a combination of visualization and technology which can be in any form of technology that changes information into images or graphics to make decision making. However, there is a lack of a teaching model that relates to the usage of technology which supports visualization in learning, [12]. For this reason, the authors were motivated to conduct this present study to provide teachers with a guideline on how to embed VT in teaching geometry. Hence, an integration of the VT pedagogical model in geometry for mathematics teachers in secondary schools needs to be built, [13].

2 Background of the Study

VT is an important element to be considered when restructuring the current curriculum for mathematics, [14]. The factors that affected teachers in using VT had been identified by a group of experts from the field of Mathematics. They were experienced teachers, lecturers from local universities, and officers from MOE. The first factor is teaching activity (TA). This term refers to activities that are prepared by teachers based on the learning objectives. Students' weakness in Geometry is due to two main reasons: low level of geometrical thinking, [15], and low visual-spatial skills (VSS), [16]. The first reason is a thinking pattern that is connected to van Hiele's geometrical thinking (vHGT) model, [17]. The lowest level in this model is visualization, where the students could only recognize the shapes of the objects. The second level is analysis, where the students can describe the properties of the objects. The third level is informal deduction, where the students will be able to prove the relationship between the properties of the objects. The next level is formal deductive, where the students will be able to form hypotheses based on their observations. The highest level is rigor, which relates to a higher thinking level that is not recommended for secondary school students, [18]. Students' thinking level will move to a higher level during their engagement in learning Geometry.

This thinking model is embedded in teaching by using van Hiele's learning phases, [17]. The first phase is information, where the students will be informed about the objectives of the lesson. The second phase is guided orientation, where teachers will give instructions and steps to students to learn the new concept. The third phase is explicitation, where the students express their opinion about the new knowledge that they learn. The fourth phase is free orientation, where the students will solve more challenging problems. The last phase is integration, where the students will make a summary of what they have learned. Meanwhile, VSS is the ability to rotate, view, transform and cut mentally, [16]. Therefore, teachers should create activities that integrate three components of vGHT, VSS, and van Hiele's learning phases, [19]. Besides that, in [20], the authors suggested hands-on activities to be conducted using technology tools to improve visualization. Moreover, in [21], the authors proposed drawing activities in learning Geometry.

The second factor is a selection of media, tools, and teaching aids (SMTTA). In [18], the author suggested that teachers should create materials that support students' thinking patterns at each level of the model. Hence, teachers should apply visualization techniques in teaching such as using concrete manipulative objects like 3D blocks and models, [22]. Another technique is using paper folding for activities such as origami, [23]. In [24], the authors suggested using computer applications in teaching. Dynamic geometrical software (DGS) such as 3D software is a good example of a computer application, [7]. The hands-on activities using tools in DGS, help students to visualize the objects, [20], [21]. However, students are facing problems in using DGS in which they cannot remember the steps of using the tools in the software, [25]. Therefore, a screencast video is used to overcome the problem. This video records all the movements of the pointer by using special software, [19].

The third factor is assessment (AST). It can be done using two types of assessment: formative and summative. Teachers must conduct tests for vGHT and VSS before and after teaching the concepts to the students. Based on the result, the teacher can determine whether the students can move to the next level of geometrical thinking, [17]. The fourth factor is teaching strategy (TS) which refers to the method or technique in delivering using digital and non-digital technology to help students in visualizing the concepts of Geometry, [26]. Teachers should evaluate their selection of teaching methods as these will affect the student's understanding, [27]. If teachers only depend on textbooks in teaching, this may cause students to recognize the shapes or diagrams but fail to solve the problems given to them, [28]. Thus, teachers should select a teaching strategy that embeds VT. This is in line with MOE that proposed technology as a teaching strategy in Mathematics to teach students to construct knowledge effectively, [10].

Hence, this study analyzes the influence factors of the integration of VT in Geometry among mathematics teachers. Thus, the following hypotheses have been framed for the study:

1. $H_0$1, the TA has a significant relationship with the integration of VT in Geometry.
2. $H_0$2, the SMTTA has a significant relationship with the integration of VT in Geometry.
3. $H_0$3, the AST has a significant relationship with the integration of VT in Geometry.
4. $H_0$4, the TS has a significant relationship with the integration of VT in Geometry.

3 Methodology

3.1 Research Design

The questionnaire used to measure the four latent variables (TA, SMTTA, AST, and TS) was developed from the literature. Data were collected from an online questionnaire distributed to secondary mathematics teachers, with 30 questions considered indicator variables. The questionnaire was divided into Part I and Part II. Part I contains items related to the respondents' demographic backgrounds while the items in Part II focus on four constructs: TA (7 items), SMTTA (7 items), AST (4 items), and TS (12 items).

3.1 Analyzing Data

For this purpose, a VT pedagogical model was suggested and verified using partial least squares structural equation modeling (PLS-SEM), to examine factors contributing to the integration of VT in Geometry. The PLS-SEM is chosen as a method to explore the relationship between the research variables, [29], [30]. It consists of two phases: testing the measurement model and the structural model. The first phase is a procedure to test internal consistency and convergence validity. The aspect of convergence validity can be seen at the values of outer loading, composite reliability (CR), and average variance extracted (AVE), while discriminant validity can be seen in Fornell Larcker, cross-loading, and Heterotrait- Monotrait Ratio (HTMT).

The aspects of convergence and discriminant validity are important in assessing the quality of results obtained from a research study that uses structural equation modeling (SEM) techniques. Convergence validity refers to the extent to which different measures of the same construct are related to one another. This can be assessed by examining the values of outer loading, composite reliability (CR), and average variance extracted (AVE). If these values are high, it means that the measures are converging on the same underlying construct, which increases the overall validity of the research study.

Discriminant validity, on the other hand, refers to the extent to which different constructs are not related to one another. This can be assessed by examining Fornell Larcker, cross-loading, and Heterotrait-Monotrait Ratio (HTMT). If these values are low, it means that the different constructs are not overlapping and are distinct from one another, which also increases the overall validity of the research study. In conclusion, the results of the research study will be more reliable and valid if both convergence and discriminant validity are adequately assessed and satisfied.

The second phase is concerning the evaluation of the structural model. The structural model's assessment includes the level and significance of the path coefficients by performing a bootstrapping procedure with 5,000 resamples, [31]. The procedure in this phase is to identify five items: internal VIF or Multicollinearity (Inner VIF), structural model coefficient (T), coefficient (R square, R^2), size effect (f^2), and predictive relevance (Q^2), [30].

4 Problem Solution

A total of 180 mathematics teachers from secondary schools in Malaysia participated in this study as shown in Table 1. The number of participants to perform the structural equation model (SEM) is between 100 to 200, [32], [33].

Table 1. Respondents' Demographic Information

Demographic Information		Total	%
Gender	Male	39	22
	Female	141	78
Age	25-30	5	3
	31-35	26	14
	36-40	29	16
	41-45	38	21
	46-50	34	19
	>50	48	27
Academic	Diploma	2	1
	Degree	127	71
	Master	51	28
Teaching Experience	1-5	20	11
	6-10	39	22
	11-15	42	23
	16-20	19	11
	>20	60	33

4.1 Measurement Model

The first element in the convergence validity is the outer load value. Table 2 shows that the results of CR ranged between 0.904 to 0.926 which were above the recommended value of 0.7, [34]. Meanwhile, the AVE values should be above the threshold of 0.5, [35], [36]. From Table 2, the AVE value for the TS constructs was <0.50. Therefore, to increase the AVE value to >0.50, items for outer loading which is <0.50 in each construct need to be eliminated, [30].

Table 2. Results For the Test of Measurement Model – Stage 1

Construct	Item	Outer loading >0.50	CR >0.70	AVE >0.50
TS	S1	0.782	0.909	**0.45**
	S2	0.788		
	S3	0.735		
	S4	0.654		
	S5	0.67		
	S6	**0.545**		
	S7	0.707		
	S8	0.745		
	S9	0.717		
	S10	0.642		
	S11	0.578		
	S12	**0.371**		
SMTTA	M1	0.832	0.904	0.577
	M2	0.831		
	M3	0.857		
	M4	0.597		
	M5	0.822		
	M6	0.599		
	M7	0.729		
TA	A1	0.813	0.913	0.603
	A2	0.664		
	A3	0.832		
	A4	0.771		
	A5	0.659		
	A6	0.844		
	A7	0.829		
AST	P1	0.801	0.926	0.757
	P2	0.885		
	P3	0.877		
	P4	0.914		

After removing the items (S12 and S6), all values of AVE reached corresponding thresholds as shown in Table 3. Even though some values for outer loading were less than 0.70, they were accepted since all AVE values were above 0.50, [30], [37]. Therefore, convergent validity was adequately indicated.

Table 3. Results For the Test of Measurement Model – Stage 2

Construct	Item	Outer loading >0.50	CR >0.70	AVE >0.50
TS	S1	0.798	0.909	0.577
	S2	0.649		
	S3	0.571		
	S4	0.797		
	S5	0.743		
	S7	0.662		
	S8	0.680		
	S9	0.696		
	S10	0.745		
	S11	0.722		
SMTTA	M1	0.832	0.904	0.577
	M2	0.829		
	M3	0.855		
	M4	0.601		
	M5	0.820		
	M6	0.602		
	M7	0.731		
TA	A1	0.813	0.913	0.639
	A2	0.661		
	A3	0.834		
	A4	0.769		
	A5	0.656		
	A6	0.845		
	A7	0.831		
AST	P1	0.802	0.926	0.757
	P2	0.884		
	P3	0.877		
	P4	0.914		

To confirm discriminant validity, the value of the square root of AVE should be higher than its correlation with other variables (based on the Fornell-Larcker criterion). The reflective construct TA had a value of 0.777 for the square root of its AVE as shown in Table 4. This value was higher than the SMTTA (0.761) and TS (0.589). However, the value for AST was above the value of TA. Consequently, it showed that there was no relationship between both variables, [38]. Therefore, the variable for teaching activity had no relationship with the variable of assessment. Meanwhile, the reflective construct for SMTTA had a value of 0.76 for its AVE. This value was higher than the AST (0.674) and TS (0.701). Similarly, the reflective construct for AST had a value of 0.87 for its AVE. This value was higher than TS (0.603).

Table 4. Inter-Correlations of The Latent Variables

Construct	TA	SMTTA	AST	TS
TA	**0.777**			
SMTTA	0.761	**0.76**		
AST	**0.78***	0.674	**0.87**	
TS	0.589	0.701	0.603	0.709

Table 5 shows the cross-loading values for each item reflected on four different latent constructs. Items A1, A2, A3, A4, A5, A6, and A7 loaded high on their corresponding construct TA and much lower on other constructs of SMTTA, AST, and TS. Items M1, M2, M3, M4, M5, M6, and M7 loaded high on their corresponding construct SMTTA and also lower on other constructs of TA, TS, and AST. Items P1, P2, P3, and P4 also appeared to load high on their corresponding construct of AST but much lower on other constructs of TA, TS, and SMTTA. Furthermore, items S1, S2, S3, S4, S5, S7, S8, S9, S10, and S11 also loaded higher on their corresponding construct of TS and lower on other constructs of TA, AST, and SMTTA. This shows that the value for cross-loading is smaller than the value for factor loading. Therefore, it indicates good discriminant validity, [39].

Table 5. Cross Loading for Constructs TA, SMTAA, AST, and TS

Item	TA	SMTTA	AST	TS
A1	**0.813**	0.623	0.67	0.507
A2	**0.661**	0.398	0.403	0.354
A3	**0.834**	0.69	0.674	0.477
A4	**0.769**	0.492	0.595	0.479
A5	**0.656**	0.368	0.392	0.361
A6	**0.845**	0.731	0.695	0.503
A7	**0.831**	0.721	0.713	0.491
M1	0.604	**0.832**	0.552	0.629
M2	0.654	**0.829**	0.562	0.509
M3	0.664	**0.855**	0.591	0.55
M4	0.407	**0.601**	0.338	0.581
M5	0.609	**0.82**	0.566	0.538
M6	0.49	**0.602**	0.392	0.436
M7	0.579	**0.731**	0.537	0.491
P1	0.593	0.49	**0.802**	0.54
P2	0.721	0.636	**0.884**	0.497
P3	0.67	0.585	**0.877**	0.552
P4	0.724	0.626	**0.914**	0.514
S1	0.393	0.495	0.448	**0.798**
S2	0.406	0.489	0.481	**0.797**
S3	0.416	0.445	0.433	**0.743**
S4	0.383	0.531	0.395	**0.662**
S5	0.476	0.498	0.456	**0.68**
S7	0.45	0.586	0.45	**0.696**
S8	0.401	0.51	0.442	**0.745**
S9	0.487	0.538	0.445	**0.722**
S10	0.426	0.513	0.4	**0.649**
S11	0.322	0.335	0.296	**0.571**

In Table 6, the HTMTs of this measurement model were all less than 1, indicating that the measurement model had good discriminant validity, [37]. Therefore, the model and scale constructed in this study had high reliability and validity, [40].

Table 6. Heterotrait-Monotrait (HTMT)

Construct	TA	SMTTA	AST	TS
TA				
SMTTA	0.842			
AST	0.856	0.757		
TS	0.657	0.8	0.677	

4.2 Structural Models in PLS-SEM

The first element is to test multicollinearity (Inner VIF) to examine whether the components of the model (TS, TA, SMTTA, and AST) are redundant to one another, [37]. The VIF value should be less than the threshold of 5, [30]. From Table 7, all inner VIF values were below the threshold of 5. Therefore, there was no collinearity issue in this case.

Table 7. Results of the Structural Model Test for Inner VIF

Construct	Integration of VT in Geometry
TS	3.446
TA	3.112
SMTTA	2.792
AST	2.097

The second element is to test the path coefficients (β) by using a bootstrapping procedure. The path coefficient should be significant if the T-statistics is larger than 1.945, [30]. Table 8 shows that all constructs had a T value > 1.645 and the highest path coefficient was TS (β = 0.358). Moreover, from Table 8, H_01, H_02, H_03, and H_04 had reached a significant level with a p-value less than 0.05. Therefore, all hypotheses were accepted.

Table 8. Structural Model Evaluation Results

Hypothesis	Mean/βeta	Standard Deviation	T Statistics (O/STDEV)	P Values <0.05
H_01	0.3	0.017	17.139	0.00
H_02	0.279	0.016	17.145	0.00
H_03	0.207	0.012	16.571	0.00
H_04	0.358	0.024	14.804	0.00

The PLS-SEM path analysis model is shown in Figure 1. The findings showed that VT should be embedded in TS, TA, SMTAA, and AST. Teachers should choose teaching strategies, activities, and teaching aids that will help the students in visualizing the concepts in Geometry by using digital and non-digital technology. For TS, teachers can use DGS for teaching 3-dimensional (3D) objects. They also can use screencast videos to help students to know the tools in the software. For TA, teachers should allow students to be hands-on with the software. Meanwhile, for SMTAA, teachers can use concrete manipulative materials such as 3D blocks and models. Furthermore, for assessment, teachers should test the student's level of VSS and vGHT before and after teaching them the concepts of Geometry.

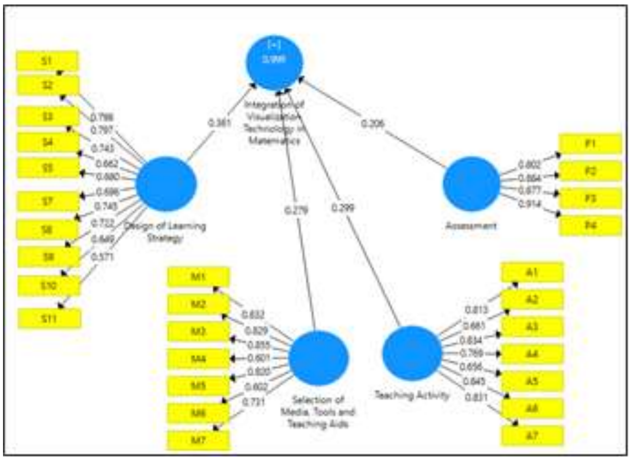

Fig. 1: Model of Integration of VT in Geometry

The third element is to test the coefficient of determination (R^2). The value of $R^2 > 0.67$ is strong, $R^2 > 0.33$ is moderate and $R^2 > 0.19$ is weak, [29]. Table 9 shows that the determination coefficient (R^2) for the integration of VT in Geometry was 0.999. Therefore, this value was considered highly acceptable. The R^2 value suggested that 99.8% of variants can be explained by the independent constructs towards the dependent construct of the research. In addition, the adjusted R^2 value was very close to the R^2 value, implying that the bias of the non-significant independent variables was very small, [41].

Table 9. Results of the Structural Model Test for R Square (R^2)

Variable	R Square (R^2)	R Square Adjusted
Integration of VT in Geometry	0.999	0.998

The fourth element is to calculate the effect size (f^2). Table 10 shows that the effect sizes (f^2) of all the dependent variables were large since the f^2 value is more than 0.35, [42].

Table 10. The Values of R^2, F^2

Factor	Endogenous	R^2 Include	R^2 Exclude	Effect Size (f^2)
TS	Integration of VT in Geometry	0.999	0.96	39.00
TA		0.999	0.978	21.00
SMTTA		0.999	0.977	22.00
AST		0.999	0.987	12.00

The final element is to find the value of Q^2 through a blindfolding procedure using SmartPLS 3.0, [39]. Results for the predictive relevance are shown in Table 11. Since the Q^2 value of 0.385 was greater than 0 with just one endogenous construct of Integration of VT in Geometry, the model was considered as having adequate predictive power, [43].

Table 11. Results of Predictive Relevance

Dependent Variable	SSO	SSE	Q^2 (=1-SSE/SSO)
Integration of VT in Geometry	5,400.00	3,322.43	0.385

5 Discussion

The main purpose of this research is to determine the influencing factors on the integration of VT in Geometry for secondary mathematics teachers in Malaysia. This research attempts to explain the relationship between TS, TA, SMTTA, and AST. This study finds that the constructs have significant relationships with the integration of VT in Geometry. The outcome of this finding is consistent with those of other studies which showed that technology had positive effects on students in learning Geometry, [44], [45]. However, in [46], the authors found out that teachers need more resources on Mathematics visualization and they also need training on how to apply visualization techniques. They also suggested that curriculum and textbooks should be designed to embed VT in the teaching and learning process. Another study also showed that VT should be integrated with initial teacher training for pre-service teachers, [47].

Furthermore, the results indicate that TS has the greatest impact on the integration of VT in Geometry (0.358). Similarly, these findings are also supported by other research which found that TS affects the integration of VT in teaching Geometry, [15], [19]. Moreover, the findings reveal that the TS using screencast video assists students in learning the tools in DGS. The findings are consistent with other studies that showed that the screencast video helped students in using new software, [49], [19]. These findings also show that the TS using visualization techniques can help students to visualize the concepts in Geometry. This result is aligned with those reported by prior studies that use these techniques in teaching Geometry, [46]. In addition, TS using technology show that students' levels of vHGT and VSS had increased, [48]. Similarly, these findings are also supported by other research which found that TS using VT increased students' level of VSS and vHGT, [19], [48].

For the TA, VT elements are applied through the use of technology tools, [11]. Meanwhile, for the SMTTA, VT elements are applied by using manipulative materials, [24], and video screencasts, [19]. The last component is AST which involves measuring the level of students' vHGT and VSS before and after teaching Geometry. Through this assessment, teachers can evaluate their TS, TA, and SMTTA that are used in teaching Geometry, [48]. These results are consistence with the previous studies that claimed that TA, SMTTA, and AST affect the integration of VT in Geometry, [1], [23].

6 Conclusion

One of the main goals of MOE is to encourage teachers to integrate technology in teaching and learning Mathematics to assist weak students in visualizing. Teachers need a new pedagogical model that integrates non-digital and digital technology in teaching. Thus, this model contributes to the literature on the integration of technology in Mathematics for secondary mathematics teachers. Moreover, MOE should realize that Mathematics curricula should be reformed to embed VT for topics in Geometry. In addition, proper programs and training should be planned by the authorities to help teachers integrate VT into their lessons effectively. Further research is proposed to study the integration of VT among teachers in other fields of Mathematics, to produce a perfect integration of the VT model specifically for secondary Mathematics teachers.

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