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MODELLING MATHEMATICAL PERFORMANCE USING TWO STAGED HYBRID STRUCTURAL EQUATION MODELLING AND ARTIFICIAL NEURAL NETWORK AMONG SECONDARY SCHOOL STUDENTS

(Pemodelan Prestasi Matematik Menggunakan Pendekatan Hibrid Dua Peringkat Pemodelan Persamaan Berstruktur dan Rangkaian Neural Buatan dalam Kalangan Pelajar Sekolah Menengah)

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ABSTRACT

Predicting students' performance is absolutely essential in both educational and machine learning contexts. The objective of the study is to determine the variables which are students' interest, teachers personality, peer influence and perceived technology that can give the significant effect on students' performance on mathematics subject through the structural equation modelling (SEM) and artificial neural network (ANN) combination. A sample comprised 302 respondents selected from a certain school in Malaysia using convenience sampling. The instrument used is online questionnaire that is validated by using exploratory factor analysis (EFA) for pilot study and confirmatory composite analysis (CCA) for field study. The model was validated using a multi-analytic approach using SEM and the results from SEM were used as inputs to the ANN model to develop a predictive model. The results of model A indicated that geometry domain has the greatest influence on students interest that can affect students score in mathematics. It is followed by discrete mathematics, statistics and probability, number and operations and algebra domain. The results of model B indicated peer influence was the most significant factor that can influence students score in mathematics, followed by students interest, perceived technology and teachers personality. The findings of this study can be critical and valuable for the school in predicting students' performance in mathematics subject. Hence, the results of this study can be used to assist teachers to formulate strategies as early as possible and to cover the stimuli affecting students' performance with appropriate measures as preparation for the students to sit for the national examination, Malaysian Certificate of Education (SPM).

Keywords: students' performance; students interest; mathematics; school; structural equation modelling; artificial neural network

ABSTRAK

Meramal prestasi pelajar adalah sangat penting dalam konteks pendidikan dan pembelajaran mesin. Objektif kajian ini adalah untuk menentukan pemboleh ubah iaitu minat pelajar, personaliti guru, pengaruh rakan sebaya dan persepsi terhadap teknologi yang boleh memberi kesan signifikan terhadap prestasi pelajar dalam subjek matematik melalui gabungan pemodelan persamaan berstruktur (SEM) dan rangkaian neural buatan (ANN). Sampel kajian ini terdiri daripada 302 responden yang dipilih dari sebuah sekolah di Malaysia menggunakan pendekatan persampelan mudah. Instrumen yang digunakan adalah soal selidik dalam talian yang telah disahkan melalui analisis analisis faktor eksploratif (EFA) bagi kajian rintis dan analisis komposit pengesahan (CCA) bagi kajian lapangan. Model ini telah disahkan dengan pendekatan multi-analitik menggunakan kaedah SEM, dan hasil keputusan daripada SEM digunakan sebagai input kepada model ANN untuk membangunkan model ramalan. Hasil daripada model A mendapati domain geometri mempunyai pengaruh terbesar terhadap minat pelajar yang seterusnya mempengaruhi pencapaian mereka dalam matematik dan diikuti dengan matematik diskret, statistik dan kebarangkalian, nombor dan operasi serta algebra.

Hasil daripada model B mendapati pengaruh rakan sebaya sabagai faktor yang paling signifikan dalam mempengaruhi markah pelajar dalam matematik, diikuti dengan minat pelajar, penggunaan teknologi dan personaliti guru. Penemuan kajian ini sangat krtitikal dan bernilai kepada pihak sekolah dalam meramalkan pencapaian pelajar dalam subjek matematik. Oleh itu, hasil daripada kajian ini boleh digunakan untuk membantu guru-guru merancang strategi seawal yang mungkin untuk menangani faktor yang memberi kesan kepada pencapaian pelajar dengan menggunakan langkah-langkah yang sesuai sebagai persediaan untuk pelajar menduduki peperiksaan kebangsaan, Sijil Pelajaran Malaysia (SPM).

Kata kunci: pencapaian pelajar; minat pelajar; matematik; sekolah; pemodelan persamaan berstruktur; rangkaian neural buatan.

1. Introduction

The Industrial Revolution 4.0 (IR4) has caused major changes in the field of education, particularly in the teaching of mathematics. The IR4's fast technological development raises important questions about how mathematics education may improve the world. Additionally, at the era of the Industrial Revolution 5.0, there is a focus on encouraging students to think creatively and integrating STEM (science, technology, engineering, and mathematics) education (Zulnaidi *et al*. 2024). The Malaysian school system has made science and mathematics a priority in order to shift to a STEM-driven economy by 2025. Therefore, in order to promote students' interest, attitudes, and knowledge of STEM-related occupations, it is now crucial to develop a workforce with a strong foundation in science and mathematics (Ministry of Education Malaysia 2013). Mathematical and science performance are compared in international assessment reports such as the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Students Assessment (PISA).

These days, participating nations evaluate one another's performance in science and maths using TIMSS and PISA as a benchmark. Reports from PISA and TIMSS also include further survey-derived insight data that can be used for further study and action. According to TIMSS and PISA data, two important factors affecting pupils' motivation in mathematics are self-efficacy and self-concept (Jaafar & Maat 2020). Inevitably, the the findings of the Trends in International Mathematics and Science Study (TIMSS) show that the majority of students tend to have difficulty solving mathematical issues (Mokhtar *et al*. 2019). The inability of pupils to answer real-life mathematical problems, their inability to comprehend concepts, their lack of basic knowledge and a variety of other difficulties are among the many issues that are commonly discussed in mathematics education in Malaysia and throughout the world, especially at the school level. In the Trends in International Mathematics and Science Study (TIMSS) 2023, Malaysia's average maths score dropped from 461 points to 411 points, which was lower from the TIMSS 2019 average (Zamzam Amin *et al*. 2024).

Furthermore, the Malaysian Education Development Plan 2013-2025 showed that 35% of Malaysian pupils were unable to fulfil the minimal competency levels in mathematics as compared to 1999. According to the study conducted by Abdullah *et al*. (2020), South Korean math problems are more challenging than those in Malaysia, which has an effect on the educational efficacy. Furthermore, the South Korean Ministry of Education has placed a greater focus on mathematical problem-solving for a longer period of time than the Malaysian curriculum does. South Korean students can therefore solve mathematical problems in higher cognitive domains than Malaysian pupils, according to the results of TIMSS and PISA examinations. The Malaysian Curriculum Education Division should review the material, particularly the mathematical problems. Mathematical problems can be made more challenging as long as they don't exceed students' cognitive load, according to cognitive load theory (Abdullah *et al*. 2020).

The Examination Board (Lembaga Peperiksaan), Ministry of Education Malaysia has created the evaluation model for SPM mathematics starting in 2021. Before switching to the Standard Curriculum for Secondary Schools, Kurikulum Standard Sekolah Menengah (KSSM) in 2017, Malaysia's national secondary schools had been using the Malaysian Integrated Curriculum for Secondary Schools, Kurikulum Bersepadu Sekolah Menengah (KBSM) since 1989. This curriculum's mathematics content domain only included numbers, shape and space and relationships (Norfadillah Zalina & Najihah 2017). Numbers and operations, geometry, algebra, statistics and probability, and discrete mathematics are the five interconnected content domains that make up the secondary level KSSM mathematics curriculum. As a result, the new format that incorporates all five curriculum domains is introduced to the students in SPM 2021. The introduction of the STEM Package (Science, Technology, Engineering, and Mathematics) has coincided with this new content domains (Bahagian Pembangunan Kurikulum 2018).

One of the most important factors in the growth of people with mathematical fikrah is the mathematics content domain. Students who are capable of doing mathematical operations, comprehending mathematical concepts, and responsibly utilising mathematical knowledge and abilities in their daily lives while being directed by positive attitudes and values are referred to as mathematical fikrah (Bahagian Pembangunan Kurikulum 2018). It supported STEM's goal of fostering students' critical thinking, problem-solving and collaborative abilities while preparing them for careers in STEM-related industries like engineering, architecture and accounting which demand a strong mathematical skills (Idris & Bacotang 2023; Zulnaidi *et al*. 2024).

Numerous algorithms including random forest, decision tree, support vector machine and regression were employed by earlier researchers to forecast students' performance according to previous research by Nawang *et al*. (2021). Using a qualitative research approach, Mohd Noorzally and Mahmud (2023) recently investigated mathematics learning loss among secondary students in Pasir Gudang, Johor. The study found that low attendance, socioeconomic issues, and a lack of basic mathematical comprehension are the main reasons of mathematics learning loss. They discovered that students' interest in mathematics was greatly impacted by the lack of understanding of fundamental mathematics. The elimination of necessary tests like the PT3 and UPSR is another factor contributing to pupils' disregard for school assessments (Mohd Noorzally & Mahmud 2023).

To get over the limitations, educators might use effective tactics like making specially designed modules that the pupils require. According to Nurrijal *et al*. (2023), in order to maintain the interest of pupils who have lost interest in learning mathematics, teachers must employ computer technology to improve their teaching methods. Teachers must adapt their methods to the needs of current generation. Since the present generation is less interested in learning that is restricted to chalk and talk, teachers must utilise fewer traditional methods in the classroom to grab students' interest in mathematics (Mohd Noorzally & Mahmud 2023).

Teachers in school started to place more emphasis on problem-solving techniques and real world applications of mathematical content domains like geometry, algebra, and calculus (Zulnaidi *et al*. 2024). Research regarding students' interests is essential because it is one of the primary factors influencing students performance (Mappadang *et al*. 2022b; Wong & Wong 2019). However, it has not been done as much in our nation (Mohd Noorzally & Mahmud 2023). So far, students' interest has only been applied as general among school students in Malaysia. By breaking down the students' interest construct into five domains according to the DSKP mathematics content domain, the study thus advances the theoretical theory of students' interest and provides a thorough framework for creating a model that can precisely determine which mathematical content domain has the greatest impact on students' performance in the mathematics subject. Nevertheless, no single study has been carried out to look into students' interests in relation to the content domain of mathematics. Thus, In order to determine which domain has the biggest impact on mathematics achievement, this study examined the students' interest based on mathematics content domain.

According to earlier research by Nawang *et al*. (2021), a variety of algorithms including random forest, decision tree, support vector machine, regression and many more were employed by earlier researchers to forecast students' performance. First, this study used a hybrid approach to increase accurate performance rather than concentrating on a single method. Researchers like Tiruwa *et al*. (2018), Thongsri *et al*. (2021), Kheirollahpour *et al*. (2020), Akour *et al*. (2022) and Aghaei *et al*. (2023) have used this hybrid approach in the field of higher education. However, all of them conducted the research among university students only. Research utilising hybrid SEM-ANN among school students has not been done. This study makes a novel contribution by applying hybrid SEM-ANN to enhance students' performance in mathematics using a real dataset of Malaysian specifically secondary school pupils. Although comparable studies have been carried out in other nations, there is a notable deficiency in locally relevant research that takes into account, the distinct socioeconomic, cultural and educational elements influencing Malaysian students. In addition, this integrative approach does not receive enough attention in the field of education, particularly at the secondary level (among school students). While research in higher education have successfully examined complex relationships using the hybrid SEM–ANN model, its application in secondary education is yet relatively unexplored. To the best of our knowledge, this is the first study to examine the factors influencing mathematics performance among school children using a hybrid SEM-ANN approach. This study closes a significant gap in the literature because no prior research has shown the use of this hybrid method at the school level.

Other than that, a thorough overview of the literature indicates that there is not a single published study in the field of education that integrates the three methods of exploratory factor analysis (EFA), confirmatory composite analysis (CCA) and artificial neural networks (ANN) into a single research framework. Thus, by combining these two approaches with the EFA, this study provides a robust framework that adds a novel perspective to research on mathematical performance. Since the model being tested is based on EFA data, the current investigation is more comprehensive. SEM often does not support the model that EFA suggests, however in this instance, the EFA result is in line with SEM recommendation based on real empirical data.

The results of this study enable schools to implement suitable approaches to address the issues influencing students' academic performance. In order to help underachieving students as soon possible and enhance their overall academic performance, we can recommend some strategic actions based on the significant factors. Students will have ample time to prepare for the national examination, Malaysian Certificate of Education (SPM). This investigation is in line with the government's aim to reduce the number of students failing the mathematics subject in the SPM examination as according to the SPM 2024 results recently, a total of 84,025 candidates failed in mathematics subject (Lembaga Peperiksaan 2025). Therefore, this study might aid in the development of new concepts for upcoming research, especially when it comes to examining learning loss in mathematics in Malaysia.

2. Theoretical Framework and Research Hypothesis

Technology acceptance model (TAM) is one of the theoretical foundation used in this study. One of the key component of TAM model is perceived usefulness (PU) which is the degree to which a student believes that using a particular technology will enhance their academic performance (Aljarrah *et al*. 2016; Kong *et al*. 2024). Other than that, theoretical interest also is utilized in this study explaining the impact of students' interest on their academic performance (Mappadang *et al*. 2022). The last theory that is applied in this research is Bandura's Social Cognitive Thoery that suggests the social context such as teachers and peer can give the significant impact on academic performance models (Bembenutty *et al*. 2016; Koutroubas & Galanakis 2022). Thus, these factors which are perceived technology, peer influence, teachers' personality and students interest are used as independent variables in this analysis.

2.1. *Relationship of students' interest with mathematics achievement*

Students' interest in learning could contribute in boosting the students' performance academically (Kpolovie *et al*. 2014). According to several studies, students' interest significantly affects their performance in mathematics. According to Tembe *et al*. (2020) research, students' interest in mathematics and their mathematical achievement were significantly correlated. The results indicate that students' interest should be encouraged since it has the potential to positively impact on academic performance. It is in line with the theoretical interest that suggests the students' interest has an impact on academic performance (Mappadang *et al*. 2022a).

It is possible that students' disinterest in mathematics is the cause of Nigeria's consistently poor mathematics results. Interest is linked to readiness or knowledge of the topic. An interest test in mathematics can be created and used to forecast students' academic achievement (Anigbo & Idigo 2015). In a similar vein, Essien *et al*. (2015) discovered a strong relationship between students' achievement and interest. Omotade *et al*. (2016) reinforce this viewpoint and provide additional evidence that there is a substantial correlation between students' academic success and their level of interest. Similarly, Mohamed and Charles (2017) reported in their journal paper that there is a significant difference among high school students' academic performance and their interest in mathematics. Poor academic achievement results from a lack of interest in mathematics, according to Arhin and Yanney (2020). The research involved the second year students of Agogo State College in Asante Akim North District, Ghana. Using a multinomial logit regression model, the study conducted by Mappadang *et al*. (2022) demonstrated that academic interest considerably influences the academic achievement.

Recently, according to Asare *et al*. (2023). students' interest in mathematics and their mathematical achievement are significantly and favourably correlated. The study demonstrated a direct and positive correlation between interest and performance, highlighting the need of fostering interest among students to raise mathematical achievement. It is followed by García-Cerdá *et al*. 2024 revealed that students' level of interest has a significant impact on their mathematical performance. In contrast to modelling questions, which they find less engaging, the study found that Spanish students are more engaged with word problems and intramathematical challenges, which result in higher achievement. More recently, according to Ragaza (2024) students' interest influences their engagement in learning activities, which in turn affects their mathematical achievement. The study focusses on how students' need, interest, practices, and seriousness about a given topic affect their overall mathematical achievement. The students interest tested in the questionnaire used by the previous research was too general. It was regarding the attitude, stress and enthusiasm of the students towards mathematics. Thus, in this study, the students' interest are specifically divided into 5 contain domain in mathematics which are algebra, statistics, number and operations, geometry and discrete mathematics. Based on this, the following hypothesis is proposed:

H1 : Students' interest has a significant effect on Mathematics achievement.

2.2. *Relationship of teachers' personality with mathematics achievement*

One factor that has been linked to students' success in mathematics is the personality of their teachers. It follows the Bandura's Social Cognitive Thoery that profonds teachers give a significant effect on academic performance (Bembenutty *et al*. 2016; Koutroubas & Galanakis 2022). Ayebale *et al*. (2020), assert that a teacher's attitude has a significant impact on students' mathematical achievement. The quality of instruction is enhanced when teachers have positive emotions in the classroom. This suggests that in order to offer teaching effectively, the factors influencing teachers' pleasant emotions should be maximised. According to another study conducted by Rasid *et al*. (2020), teachers can significantly influence the learning environment by posing questions that encourage students to think critically and to use mathematical concepts and arguments. Additionally, according to a recent study, teachers' enthusiasm, resourcefulness, and helpful behaviour, together with their in-depth subject-matter skills and ability to make mathematics interesting, all contribute to students' positive attitudes towards mathematics subject (Tamukong *et al*. 2017).

According to a recent study by Iddrisu *et al*. (2023), teacher's teaching style, credentials, material mastery and relationships with students all affect how well students succeed in mathematics. This teacher's personality has a big impact on students' mathematics achievement. More recently, Zulnaidi *et al*. (2024) claimed that the connection between mathematics teachers' collaboration and preparedness for the industrial revolution is one of an essential topics in education today. Teachers of mathematics subject play a crucial role in preparing their students for the future and their cooperation can significantly impact on students' readiness to face the challenges of the industrial revolution (Zulnaidi *et al*. 2024). It is supported by Tengaa (2024) stated that students' self-efficacy in mathematics is greatly influenced by their teachers' enthusiasm, empathy, encouragement, warmth and adaptability, all of which enhance academic performance. Students are inspired and perform better in mathematics in a warm environment that is cultivated by positive attributes. Based on this, we propose the second hypothesis:

H2 : Teachers' personality has a significant effect on Mathematics achievement.

2.3. *Relationship of peer influence with mathematics achievement*

Peers who are friends of the same age as classmates can influence a student's behaviour, personality development and moral development. Peers also have a big impact in students' affective engagement (Bakar *et al*. 2021). According to earlier research, peer tutoring interactions have a good and significant impact on students' learning of mathematics (Alegre *et al*. 2019). Most students like the idea of getting help from their peers during the learning process. Since peer tutors study or have studied the same academic subjects as their peers, they are well aware of the difficulties that their peers may encounter (Alegre *et al*. 2020). High-level cognitive work may be possible when students share their mathematical ideas with classmates or in groups. Their ability to communicate mathematical ideas with their classmates had a favourable effect on them (Kele 2018). It confirms the Bandura's Social Cognitive Thoery that peer influence is one of the significant factor that can affect the academic performance (Koutroubas & Galanakis 2022)

Apart from that, Uzezi and Deya (2017) research indicates that peers can affect students' academic performance. Pupils who struggle to fit in with their peers are more likely to struggle academically in school. Since students prefer to ask their peers for help rather than their teachers, peer influence usually becomes more prevalent in their learning (Bergey *et al*. 2019). According to Pasco (2021), peer pressure had a major impact on students' math performance at Casisang National High School in the Philippines indicating that peers had a considerable impact on academic success.

More recently, according to Rahman and Abdullah (2024), interaction with peers has a significant impact on elementary students' mathematics learning since group projects involving communication enhance their comprehension. The study found that discussions in groups can foster idea sharing and encouragement. Thus, group discussion is an effective tool for improving students' mathematical skills. Therefore, the following hypothesis is proposed:

H3 : Peer influence has a significant effect on Mathematics achievement.

2.4. *Relationship of perceived technology with mathematics achievement*

One teaching strategy that may be used across the curriculum to help students excel in mathematics is the integration of technology into the classroom pedagogy. Technology Acceptance Model (TAM) believes that using technology will improve students academic performance (Kong *et al*. 2024).Students can become more involved in the learning process, increase their accuracy on computational tasks, reduce stress in the mathematics classroom, become more motivated, and comprehend the mathematical material more deeply when technology is used in the classroom (Murphy 2016). Eyyam and Yaratan (2014) conducted an experiment in a private school in North Cyprus to figure out if using technology in the classroom improved seventh-grade students' performance in math classes. Students who received technology-assisted instruction performed much better on mathematics post tests than students who did not get technology instruction according to the statistical test. In today's society, it is thought that integrating technology into the classroom improves students' performance and attitudes towards learning (Eyyam & Yaratan 2014). Evaluation of the impact of multimedia use on secondary school students' performance in mathematics was conducted in Lagos State, Nigeria. The experimental group that received training using multimedia aids had a higher mean score than the control group that received traditional instruction according to Akinoso (2018).

By understanding each student's needs, increasing engagement, providing targeted practice and helping students grasp mathematical concepts more deeply, technologies like AI-powered tutors, adaptive learning platforms and intelligent feedback systems significantly improve mathematical performance. Teachers and parents should also be aware of how technology can be used to teach mathematics in order for them to understand the significance of integrating technology into their teaching and learning strategies (Kattunilam 2024). Stathopoulou and Mastrotheodorou (2024) stated that in recent years, technology has significantly aided educational interventions for those with low IQs, boosting their performance in mathematics particularly through programs that aid in the development of fundamental mathematical skills. Based on this, the following hypothesis is proposed:

H4 : Perceived technology has a significant effect on Mathematics achievement.

Thus, SEM starts with a hypothesis that the researcher wants to test to see if there is a relationship between the constructs of students' interest, the first hypothesis (H1), teachers' personality (H2), peer influence (H3) and perceived technology (H4) with the mathematics achievement in the study. The relationships are depicted into a conceptual framework represented by a schematic diagram in Figure 1.

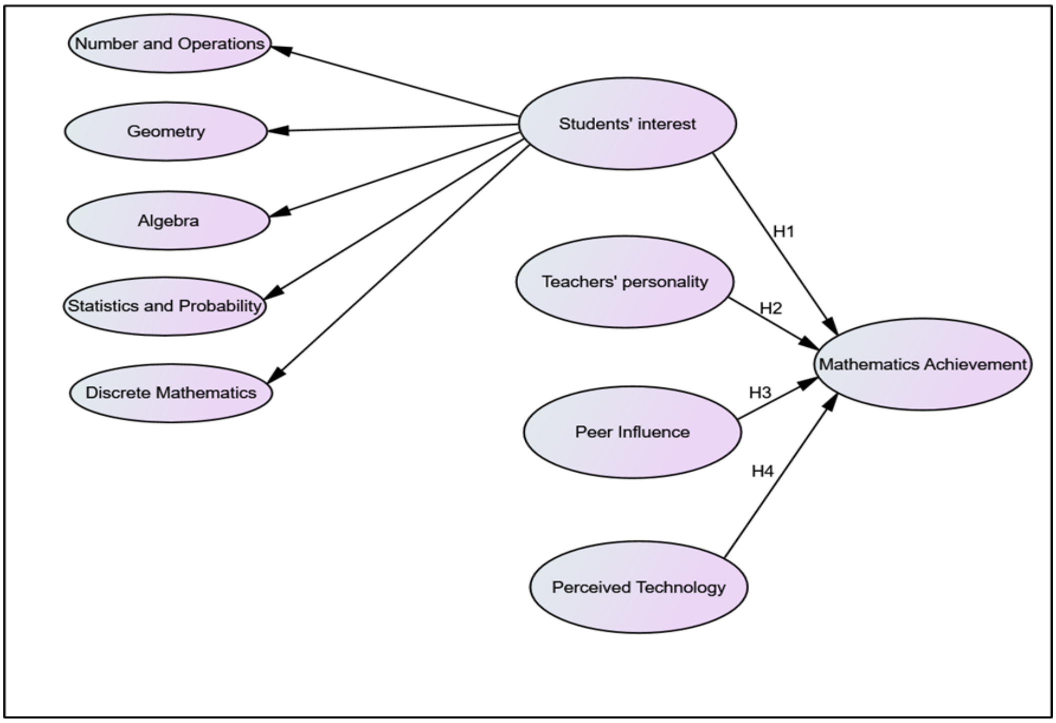

Figure 1 : Conceptual framework

3. Material and Methods

3.1. *Study area and data collection*

Sampling techniques are procedures used to take samples from a population, typically in a way that makes it easier to determine a hypothesis about the population (Parker & McGraw-Hil 2003). 302 students completed a survey that was regarded as a field study. The sample size is chosen based on the minimum sample size required suggested bay Hair *et* al. (2017) using minimum R^2 method. This study has eight number of arrows pointing at a endogenous construct (score). According to Hair *et al*. (2017), the minimum sample size required for the field study should be 174 respondents in order to obtain as minimum as possible the R^2 in the model to avoid underpowering our study. A questionnaire instrument was used to collect data from secondary students at the end of the year in a particular Malaysian school. The students are between the ages of thirteen and seventeen years old. Data was gathered using convenience sampling technique. The sample is selected from among potential respondents who meet the requirements and are open to participating in the survey (Murairwa 2015). Data for the study is obtained from volunteer participants (voluntary sampling approach). The information gathered is accurate, comprehensive, suitable, and reliable (Murairwa 2015).

3.2. *Instrument design*

The study's instrument is a questionnaire. The items in the questionnaire were created using a variety of references and sources in order to create the scale. An online questionnaire was used to gather data from secondary students in a particular Malaysian school. In order to gauge students' interest, the questionnaire is divided into five content domains: number and operations (8 items), geometry (8 items), algebra (10 items), statistics and probability (9 items) and discrete mathematics (9 items). It is followed by perceived technology (10 items), teachers' personality (13 items) and peer influence (11 items). An interval between 1 and 10 is the optimal measurement scale. Therefore, the need for parametric analysis is satisfied because the data measure is more independent (Awang 2015). After a thorough literature research, the questionnaire's contents were created. The questionnaire's material for the student interest construct was derived from Asiedu (2020), Awang (2012) and Sarikaya *et al*. (2018). The questionnaire was created using information from Awang (2012), Kirkwood and Price (2016) and Peart *et al*. (2017) regarding perceived technology. The teachers' personality was created based on earlier studies (Abdali *et al*. 2016; Awang 2012; Honu *et al*. 2019). Peer influence questionnaire material was generated based on research by Awang (2012), Sarah *et al*. (2016) and Uzezi and Deya (2017).

3.3. *Structural equation modelling and artificial neural network*

Structural equation modeling is a broad phrase that refers to a variety of statistical models that are used to test the validity of substantive theories with empirical data. One of the benefits of structural equation modeling is that it can be used to investigate the relationships among constructs that are indicated by multiple measures. Artificial neural network (ANN) improves the power of analyzing large amounts of data that are difficult to simplify using conventional statistical technique. It can also detect non-linear relationships between dependent and independent variables implicitly. Figure 2 shows the study methodology's graphical form. The technique begins with the development of the instrument as shown in Figure 2. A thorough literature research and pre-testing by the expert and students were used in the creation of the questionnaire. For the pilot project, 105 students have volunteered. The information gathered from the online survey is recorded. EFA is used to analyse the data with SPSS software in order to verify and assess the questionnaire's reliability. Following validation, a field study with 302 students who consented to respond to the online survey is conducted. Using PLS-SEM (SmartPLS software), recorded data from 302 students is analysed using Confirmatory Factor Analysis (CFA). To examine the non-linear relationship, the latent scores from the PLS-SEM output are fed into an ANN. The evaluation is the final phase. SEM, ANN, and hybrid SEM-ANN RMSE values are computed to compare which approach will produce the best (smallest) RMSE value.

4. Results

In this section, the results of the study are discussed.

4.1. *Measurement model testing*

In this study, the variance-based statistical analytical model known as PLS-SEM is used. This investigation makes use of the SmartPLS software (Binsawad 2020). There were two steps in the data analysis process. Assessing the measurement model's discriminant, convergent validity and reliability was the initial stage. After that, analysing the structural model's hypotheses is conducted using Smart-PLS software, this study performed a reliability analysis of the questionnaire items.

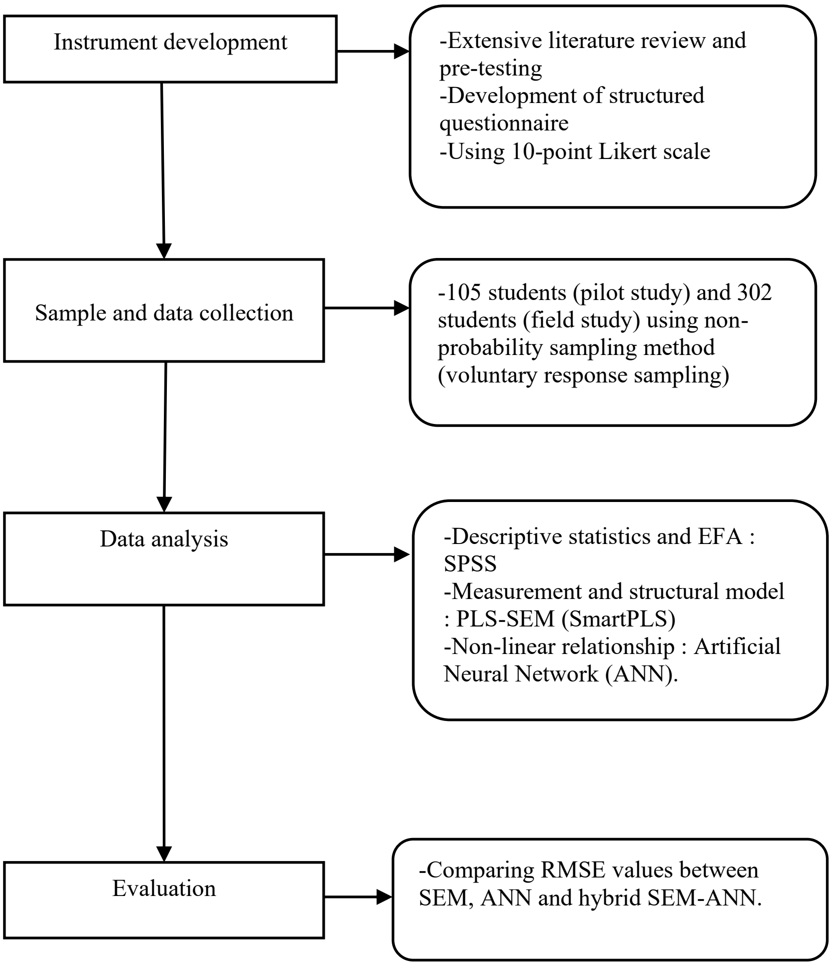

Figure 2 : Overview methodology

Each variable's Cronbach's alpha coefficient, composite reliability (CR) and average variance extracted (AVE) were recorded in Table 1 and Table 2. Cronbach's alpha, a measure of internal consistency is used to assess the instrument's reliability. Every factor's Cronbach's alpha must be higher than the suggested cutoff of 0.70 (Hair *et al*. 2010). Good convergent validity of the scales employed in the study is indicated by the composite reliability (CR) values for each variable above the normal threshold of 0.7 and the average variance extracted (AVE) for each variable exceeding the usual threshold of 0.7 (Zhou *et al*. 2024).

Table 1: Cronbach's alpha for students' interest

Component	Value of Cronbach's alpha (above 0.7)	CR (above 0.7)	AVE (above 0.5)
Statistics	0.980	0.983	0.876
Geometry	0.982	0.985	0.888
Number and operations	0.883	0.928	0.811
Algebra	0.968	0.973	0.800
Discrete	0.985	0.987	0.894

Table 2: Cronbach's alpha for main constructs

Component	Value of Cronbach's alpha (above 0.7)	CR (above 0.7)	AVE (above 0.5)
Perceived technology	0.971	0.975	0.830
Teachers' personality	0.952	0.958	0.698
Peer influence	0.913	0.933	0.699

4.2. *Structural model analysis*

These constructs will be put together into the structural model in order to perform SEM when the confirmatory composite analysis is finished and measurement models for each of the model's latent constructs have been verified. The relationship between students' interest, perceived technology, teachers' personality, peer influence and students' academic performance was evaluated using the structural model. The hypothesis statement for every path in this study and its conclusion are presented in Table 3. If *p*-values are found less than 0.05, the null hypothesis is rejected and so alternative hypothesis is accepted. Based on the results of the Table 3, the study has proved that these constructs namely students' interest, teachers' personality, peer influence and perceived technology have significant at 0.05 and direct effect on Mathematics achievement (H_1, H_2, H_3 and H_4). Based on the path coefficient, peer influence gives the most significant effect on mathematics achievement. It if followed by students' interest, perceived technology and teachers' personality.

Table 3: Hypothesis testing

Component	**Path coefficient**	***p*-value**	**Result**
H_1 : Students' interest has a significant effect on Mathematics achievement.	0.295	0.000	Supported
H_2 : Teachers' personality has a significant effect on Mathematics achievement	0.210	0.000	Supported
H_3 : Peer influence has a significant effect on Mathematics achievement.	0.316	0.000	Supported
H_4 : Perceived technology has a significant effect on Mathematics achievement.	0.228	0.000	Supported

The result for adjusted value, which the model explains by approximately 0.567 or 57%, is displayed in Figure 3. An artificial neural network (ANN) will be used in the second phase of SEM to rank the four constructs that have affected mathematics achievement after the first phase of SEM has revealed them. The SEM method identified the variables that have a significant impact on the dependent variable. The latent variables score of the significant constructs obtained in SEM is utilized as inputs and students score is used as output for the ANN to predict the relevant importance of each predictor's variable. ANN can predict the impact of the independent variables on the dependent variable and rank them by calculating the average importance of the input variables.

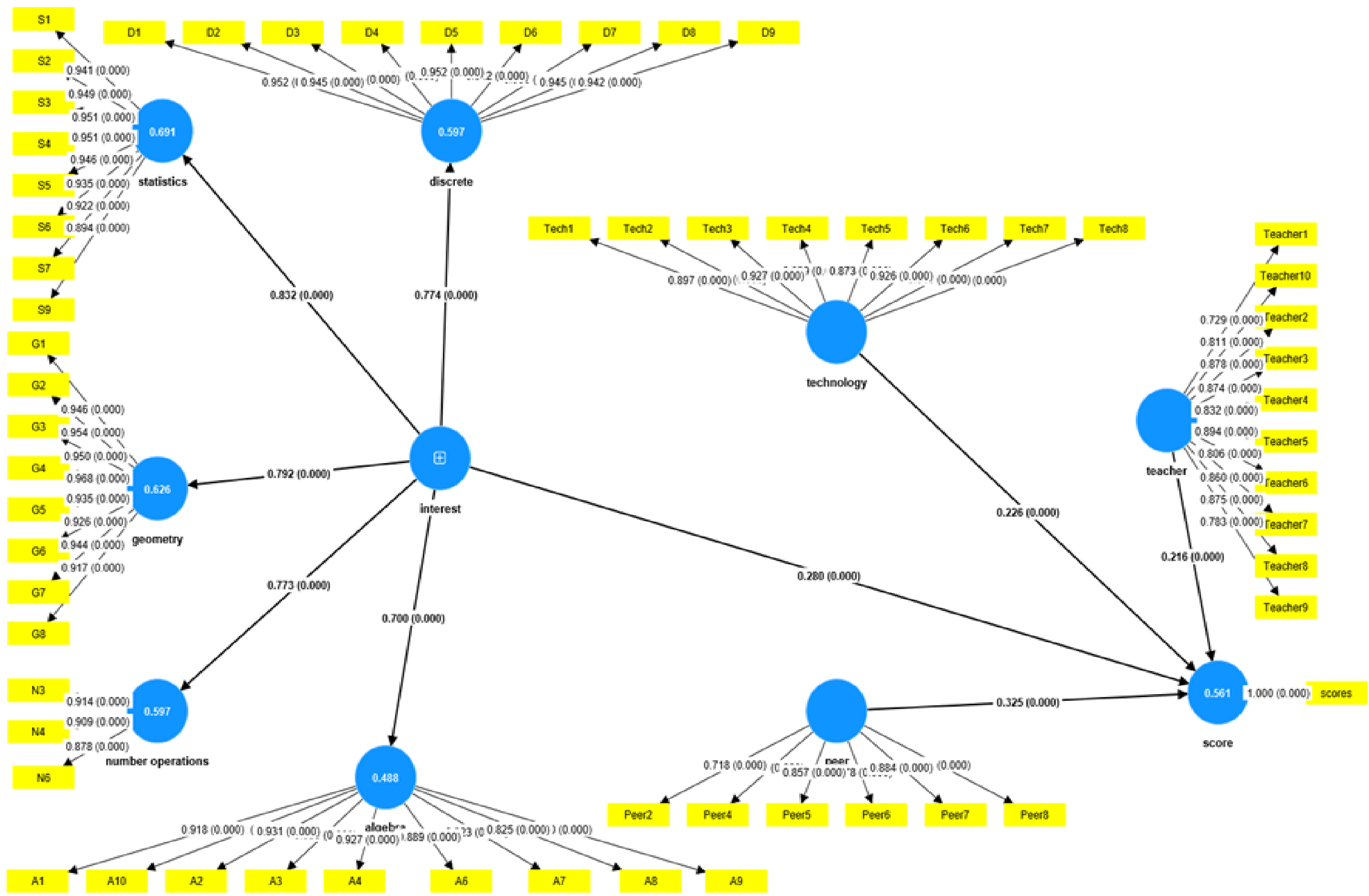

Figure 3 : PLS research model

4.3. *Artificial neural network (ANN)*

Traditional statistical techniques such as SEM and multiple regression analysis are insufficient to understand and forecast the complexity of human decision-making (Joshi & Yadav 2018). The underlying complexity of choice adoption is oversimplified due to their tendency to only examine linear models (Liébana-Cabanillas *et al*. 2018). It is advised to use ANN, one of the most effective and powerful artificial intelligence systems to solve the issue. The ANN technique can be used to identify both linear and non-linear relationships (Chong 2013).

The research model will be broken down into ANN models, as illustrated in Figures 4 and 5 because the study's model has two dependent variables. Model A has five inputs (algebra, statistics, geometry, number and operations and discrete mathematics) and one output (students' interest) whereas model B has four inputs (students' interest, perceived technology, peer influence and teachers personality) and one output (mathematics score). Both models have a single hidden layer and SPSS software will generate the number of neurones in the hidden layer (Alkawsi *et al*. 2021). The sigmoid was used as an activation function in the output and hidden layers. The model is trained using 90% of the data, with the remaining 10% being utilised for testing (Alkawsi *et al*. 2021).

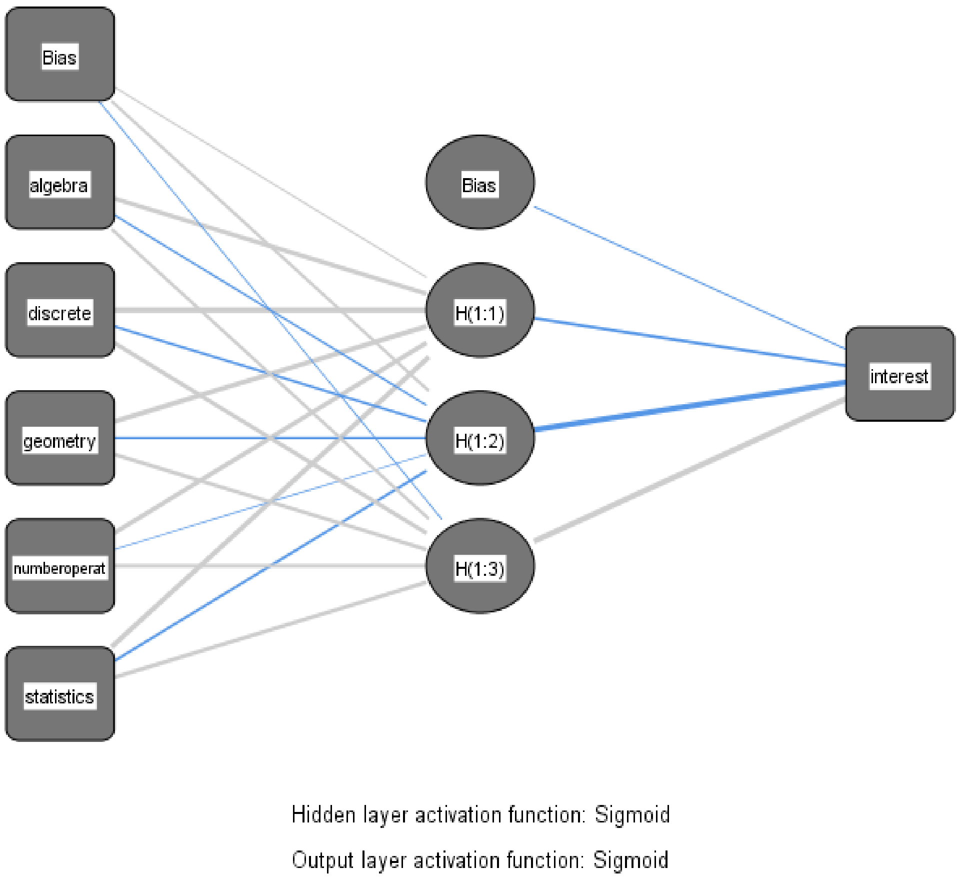

Figure 4 : Model A

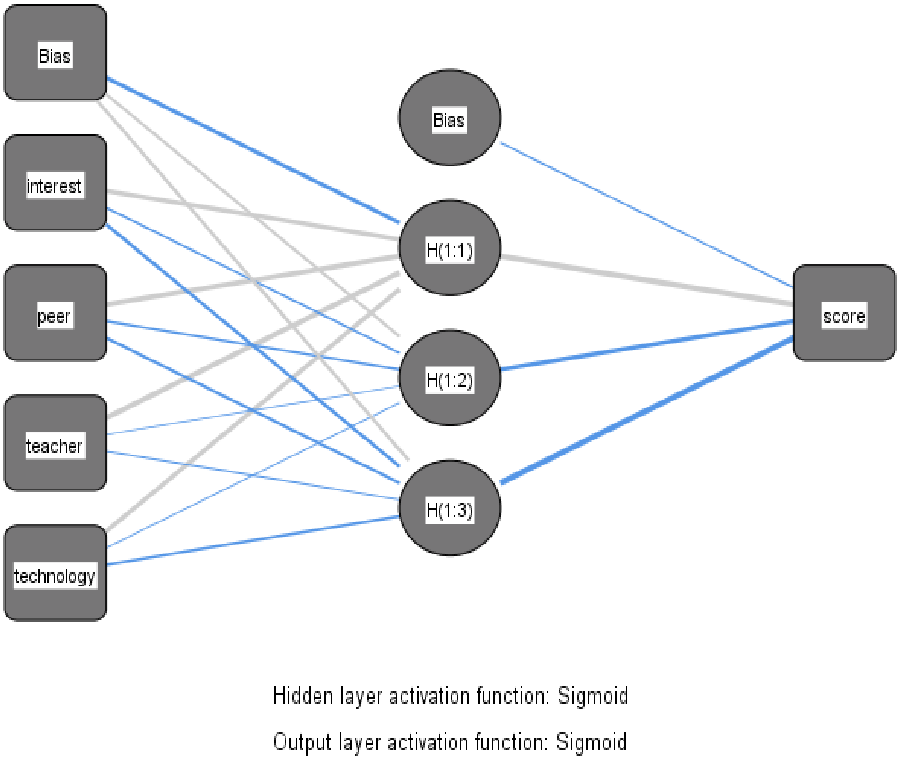

Figure 5 : Model B

The study undergoes ten-fold validation to prevent over-fitting (Liébana-Cabanillas *et al*. 2017). To assess the predicted accuracy of the model, the Root Mean Square of Error (RMSE) is calculated for each of the ten neural networks for both data sets, which are shown in Tables 4 and 5 (Liébana-Cabanillas *et al*. 2017). Table 4 shows that the average cross-validated RMSE for training model A was 0.072 and for testing model was 0.062. The corresponding standard deviations are 0.0017 and 0.0052. A prediction that is accurate is indicated by smaller RMSE and standard deviation values (Liébana-Cabanillas *et al*. 2017).

Table 4: RMSE values for model A

Network	Model A	
	Training	Testing
ANN1	0.074	0.068
ANN2	0.070	0.064
ANN3	0.071	0.063
ANN4	0.070	0.054
ANN5	0.074	0.061
ANN6	0.071	0.066
ANN7	0.069	0.065
ANN8	0.073	0.059
ANN9	0.072	0.068
ANN10	0.072	0.055
Average	0.072	0.062
Standard deviaton	0.0017	0.0052

The average cross-validated RMSE for training model B was 0.081, and for testing model, it was 0.068, as shown in Table 5. The corresponding standard deviation values, which were 0.0026 and 0.0105, respectively, are comparatively small, indicating that model B's performance is reliable. Model B indicates that the independent constructs which are students interest, peer influence, teachers personality and perceived technology have significant effect on the dependent construct which is students' score as depicted in Figure 5.

Table 5: RMSE values for model B

Network	Model B	
	Training	Testing
ANN1	0.079	0.072
ANN2	0.086	0.059
ANN3	0.079	0.064
ANN4	0.079	0.054
ANN5	0.080	0.090
ANN6	0.081	0.063
ANN7	0.085	0.073
ANN8	0.083	0.079
ANN9	0.081	0.065
ANN10	0.080	0.063
Average	0.081	0.068
Standard deviation	0.0026	0.0105

4.4. *Sensitivity analysis*

Each predictor's contribution to the endogenous construct was assessed using sensitivity analysis. Each independent variable's importance is determined by how much the value that the network model predicts changes depending on the independent variable's value (Liébana-Cabanillas *et al.* 2017). We employed sensitivity analysis to determine each input neuron's normalised relevance by dividing its relative value by its greatest importance and expressing the result as a percentage in order to evaluate the prediction power of each neuron (Xu *et al.* 2024). Table 6 shows the results of sensitivity analysis for model A consisted geometry, discrete mathematics, statistics and probability, number and operations and algebra. It also presented the average importance and normalized importance (%) of all the constructs related to the neural network.

Table 6: Sensitivity analysis for model A

NN	Geometry	Discrete	Statistics & probability	Number & operations	Algebra
ANN1	0.249	0.226	0.230	0.197	0.097
ANN2	0.278	0.256	0.178	0.219	0.069
ANN3	0.271	0.262	0.169	0.226	0.072
ANN4	0.274	0.227	0.223	0.208	0.068
ANN5	0.257	0.202	0.200	0.174	0.167
ANN6	0.264	0.261	0.166	0.190	0.118
ANN7	0.296	0.239	0.193	0.184	0.088
ANN8	0.267	0.225	0.235	0.146	0.127
ANN9	0.259	0.239	0.199	0.203	0.100
ANN10	0.252	0.251	0.184	0.229	0.085
Average importance	0.2667	0.2388	0.1977	0.1976	0.0991
Normalized importance (%)	100	89.7	74.4	74.3	37.5

The sensitivity analysis for model B, which ranks the relative relevance of the input neurones, is displayed in Table 7. According to the findings, peer pressure had the most impact on students scores, followed by students' interest, perceived technology, and the personality of their teachers.

Table 7: Sensitivity analysis for model B

NN	Peer	Students interest	Perceived technology	Teachers personality
ANN1	0.338	0.298	0.209	0.155
ANN2	0.278	0.262	0.233	0.227
ANN3	0.321	0.298	0.229	0.153
ANN4	0.309	0.320	0.225	0.147
ANN5	0.333	0.298	0.227	0.142
ANN6	0.305	0.250	0.245	0.199
ANN7	0.275	0.265	0.204	0.257
ANN8	0.299	0.178	0.219	0.303
ANN9	0.297	0.303	0.190	0.210
ANN10	0.326	0.303	0.226	0.145
Average importance	0.3081	0.2775	0.2207	0.1938
Normalized importance (%)	100	90.1	71.9	64.1

4.5. *Model accuracy improvement*

Since every path leads to the endogenous score, the dependent variable score (model B) is the subject of the accuracy value study. As shown in the table below, the RMSE can be used to gauge the accuracy levels of PLS-SEM, ANN, and hybrid model SEM-ANN analysis results. Table 8 demonstrates that the SEM-ANN hybrid model outperformed PLS-SEM and ANN alone in terms of accuracy by comparing the lower RMSE values. Hybrid SEM-ANN method used latent variables score obtained from the PLS-SEM method as the input for ANN model whereas for the standalone ANN model, the inputs used are based on mean scores of 6 items for peer influence, 8 items for perceived technology, 10 items of teachers' personality and 37 items for students' interest obtained from the collected real data (N=302) using the questionnaire. The scores obtained from the questionnaire are often noisy and imperfect due to external factors such as misunderstanding the questions. Latent variables score take out the shared variance among its indicators. It removes the random error and measurement noise. Thus, the cleaner and reliable data (latent variables score) is used for hybrid SEM-ANN method that improves the prediction of the construct.

Based on Table 8, the RMSE score for the standalone PLS-SEM method is the highest compared to the others which is 0.676. It is due to the method is capable on evaluating linear relationships only. The RMSE score for using standalone ANN method is 0.084 for training and 0.081 for testing which is higher than using hybrid method SEM-ANN which gives the values 0.081 for training and 0.068 for testing.

Table 8: The comparison of model accuracy for PLS-SEM, ANN and hybrid SEM-ANN

Dependent variable	PLS-SEM	ANN		SEM-ANN	
		Training	Testing	Training	Testing
RMSE Score	0.676	0.084	0.083	0.081	0.068

5. Simulation Data

The simulation study for this study had been conducted by simulating 500 and 1000 observations. This simulated study is conducted to verify the model's validity and reliability in real-world situations. R software is used to generate the data. Figure 6 displays the simulation data flow chart. First, the structure and properties of the original data, including variables, mean, and variance, are used to define the data generation process (defDATA). Then, using the Bayesian bootstrapping method, the synthetic data is produced. The mechanism of this method is assigning random weights to each observation. These weights are not arbitrary. They are drawn from a Dirichlet distribution which these weights sum must be equal to one. Using genDATA, 1000 observations are required. The generated data can be useful for the simulations because it closely resembles the original data. Lastly, using recalib in R software, the created data's values are rescaled to have minimum and maximum values that are identical to the original data's range of 1 to 10.

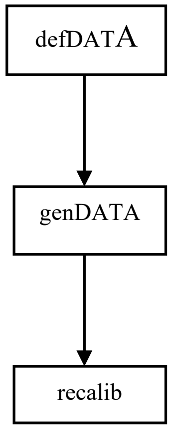

Figure 6 : Flow chart of simulation data

As advised by many scholars, this study evaluated the predicted accuracy and predictive relevance of the ANN analysis results using the widely used accuracy-measured value, Root Mean Square Error (RMSE) (Xu *et al*. 2024). Greater prediction accuracy and a strong fit and forecast for the data are indicated by a lower RMSE number. Ten-fold cross-validation of ANN and hybrid SEM-ANN approach RMSE values is displayed in Tables 9 and 10. In order to prevent overfitting, the simulation used 90% of the data for network training and the remaining 10% for testing (Xu *et al*. 2024).

Table 9 shows that the hybrid SEM-ANN approach's RMSE values for the simulation data (500 data) are lower than the ANN method alone. The hybrid model's average cross-validated RMSE is 0.112 for the training model and 0.106 for the testing model. For the Table 10, the ANN method's training and testing model RMSE values for 1000 simulation data are 0.107 and 0.107 respectively. Using the hybrid SEM-ANN approach, the training and testing phases produced average RMSE values of 0.105 and 0.106 respectively.

Table 9: RMSE values for ANN and hybrid SEM-ANN methods (500 observations)

Network	ANN		Hybrid SEM-ANN	
	Training	Testing	Training	Testing
ANN1	0.110	0.127	0.109	0.112
ANN2	0.115	0.082	0.109	0.107
ANN3	0.114	0.093	0.119	0.111
ANN4	0.120	0.142	0.108	0.119
ANN5	0.114	0.101	0.109	0.107
ANN6	0.113	0.099	0.111	0.091
ANN7	0.112	0.113	0.122	0.096
ANN8	0.113	0.100	0.112	0.102
ANN9	0.113	0.105	0.109	0.106
ANN10	0.112	0.107	0.110	0.109
Average	0.114	0.107	0.112	0.106

Table 10: RMSE values for ANN and hybrid SEM-ANN methods (1000 observations)

Network	ANN		Hybrid SEM-ANN	
	Training	Testing	Training	Testing
ANN1	0.106	0.105	0.104	0.109
ANN2	0.105	0.111	0.104	0.101
ANN3	0.106	0.094	0.103	0.106
ANN4	0.105	0.109	0.104	0.106
ANN5	0.105	0.105	0.104	0.101
ANN6	0.106	0.103	0.103	0.117
ANN7	0.105	0.118	0.105	0.099
ANN8	0.106	0.100	0.104	0.094
ANN9	0.106	0.096	0.117	0.127
ANN10	0.119	0.132	0.104	0.100
Average	0.107	0.107	0.105	0.106

The comparison of RMSE values across the three approaches which are SEM, ANN and hybrid SEM-ANN methods is shown in Table 11. In the standalone PLS-SEM model, the input consists of simulated data (500 and 1000 data) generated by the actual data collected. For the standalone ANN method, the inputs are based on the mean scores of items corresponding to specific independent constructs from the simulated data. For the hybrid SEM-ANN method, the inputs consist of simulated data derived from the field data. Subsequently, latent variables scores are produced and serve as the input for the ANN method. In comparison to the SEM and ANN methods alone, the hybrid SEM-ANN generated lower RMSE values for both simulation data (500 and 1000 data). This indicated that the suggested model was a valid and reliable way to describe the population.

Table 11: Comparison of RMSE values for the simulation data (500 and 1000 data) using SEM, ANN and hybrid SEM-ANN

Number of data	PLS-SEM	ANN		SEM-ANN	
		Training	Testing	Training	Testing
500	1.033	0.114	0.107	0.112	0.106
1000	1.014	0.107	0.107	0.105	0.106

6. Discussion and Implications

The primary goal of this study is to create a statistical model that uses hybrid structural equation modelling and artificial neural networks to improve secondary students' performance in mathematics. The majority of researchers in the field of education only used the hybrid approach with college students (Kheirollahpour *et al*. 2020; Thongsri *et al*. 2021; Tiruwa *et al*. 2018). No prior research has used a two-stage hybrid approach to examine the factors influencing school students' academic performance. Therefore, the purpose of this study is to apply the hybrid approach to secondary school students at a particular Malaysian school. This study is also practically important since it helped the relevant educational authorities comprehend the importance of each element and made plans and efforts based on the factors' relative importance.

Based on the results, it is obvious that the two stages tests (SEM and ANN) which can analyse linear and non-linear relationships respectively have successfully verified the suggested model. Based on Table 1 and Table 2, the values of Cronbach's alpha, composite reliability and AVE fulfilled the requirement for internal consistency reliability and convergent validity. It indicates that the model has passed the measurement model requirement. The research is valid for further analysis which is structural model. Based in Figure 2, the study consisted of 8 latent variables and 1 dependent variable which score. The model also conducted hierarchical component model which is reflective-reflective model of students interest. The endogeneous construct produced adjusted R^2 value approximately 57% which revealing the exogeneous constructs have impacted the mathematics score among students.

According to SEM results, every component examined had a substantial impact on mathematics achievement with a p-value for T-Statistics less than 0.5. The findings highlight the significance of peer pressure, teachers' personalities, students' interest and perceived technology and also their indisputable contribution to mathematical achievement. It is clear that the most significant factor influencing mathematics achievement was peer influence. The findings are consistent with those of the study carried out by Khan *et al*. (2023). Peer relationships and academic achievement were found to be significantly positively correlated. One of the factors that influences academic achievement is students' interest. The earlier research done by Pérez-López & Ibarrondo-Dávila (2020) supports it. According to the study, students' prior interest in an accounting course at the University of Granada in Spain is positively and significantly correlated with their academic progress. It is followed by perceived technology as suggested in the literature (Murad *et al*. 2019). The study found that educational technology has a significant influence on Ahlia University students' performance in terms of perceived usefulness and usability. Next construct is teachers' personality. According to Khan *et al*. (2016), a teacher's personality is one of the most crucial components of their professional attitude and has a significant influence on students' academic performance.

The theoretical implication from this study are the teachers are able to identify which construct that give the most impact to students performance in mathematics subject. Based on the results, peer influence has the most significant effect on students mathematics achievement. Thus, school can provide a specific program that involving students (peer) who serve as a mentor to their friends (peer mentoring program) as early as possible. This collaborative learning technique enable the students of similar skill levels are paired to help and guide each other. Mentees frequently feel better at ease asking someone who is similar to them in age or experience level for help.

Based on students' performance, the ANN technique is anticipated to rank the mathematics content domain. As a result, teachers can determine which subject area they should prioritise for their students. According to the study, geometry is the subject that has the biggest influence on students' performance. Therefore, educators must take action to encourage students interest in geometry. Teachers can use technology to improve their teaching. A technology-based instructional module is crucial for the study of three-dimensional (3D) geometry. According to current research conducted by Hashim *et al*. (2023), teachers need a technology-based module to teach 2D geometry classes because it has an impact on students' performance. Discrete mathematics is a second important area. It is followed by statistics and probability, number and operations and algebra.

For the practical implication, the government also can ensure the efficient allocation of resources to enhance academic performance. The government can provide adequate funding for public schools to guarantee that public schools have access to essential resources like technology, textbooks and learning materials as we know that the use of technology is essential for the students to learn the geometry topic. Other than that, one of the services the government may offer to improve teaching quality is funding teacher training programs such as learning using technology in the classroom such as plickers cards game. Educational authorities are encouraged to align examination questions with the mathematics content domains with particular emphasis on the geometry domain due to its substantial impact on students' score in mathematics subject.

The findings can be used as a guide to formulate strategies to improve various ministry programs and initiatives as well as teacher delivery methods and techniques in the classroom. The study's findings also helped the authorities oversee innovative and learning activities to encourage students' interest in lifelong learning.

7. Conclusion

In conclusion, all the exogeneous constructs which are students' interest, teachers personality, peer influence and perceived technology clearly give the significant effect on the students' performance on mathematics subject. The study successfully proven and validated through the structural equation modelling (SEM) and artificial neural network (ANN) combination.

The findings of this research confirm that all the independent variables tested which are students' interest, peer influence, teachers' personality and perceived technology give the signicant effect on students mathematics performance. For the mathematics content domain, geometry is the most significant domain that can affect the students mathematics score. This research can be further improved by addressing the identified limitations and incorporating them into future studies.

Specific criteria derived from the prior literature review were applied in the research. Additional characteristics such as the students' hometown, parents' occupations and family income should be included in future research. Students from a particular Malaysian school were chosen for this study using the non-probability sampling technique (voluntary response sampling). There may not be many responses. To expand the findings' generalisation and enhance the model of students mathematical performance, the researcher could also conduct numerous schools from different states in future studies.

This model is implemented in secondary school only. It is important to determine at an early age which factors have the most influence on mathematics achievement. Primary school students could be the subjects of the study in the future in order to improve academic performance by giving teachers more time to help students become proficient in mathematics and increase their interest in the subject.

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