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PROCESS VIRTUALIZATION REQUIREMENTS AND STUDENTS' SATISFACTION WITH ONLINE MATHEMATICS LEARNING

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Abstract:

Online learning has become an important component of higher education, providing students with flexible access to learning materials, instructional activities, and communication regardless of time and location. Although previous studies have examined student satisfaction with online learning, limited attention has been given to the role of Process Virtualization Theory (PVT) requirements in explaining students' satisfaction, particularly in the context of online Mathematics learning. This study aims to examine the relationships between six PVT requirements, namely sensory requirements, relationship requirements, synchronism requirements, representation, reach, and monitoring, and students' satisfaction with online Mathematics learning. Data were collected from 185 undergraduate students enrolled in Calculus courses through a structured online questionnaire and analysed using the Statistical Package for the Social Sciences (SPSS). The results indicate that the overall regression model was statistically significant and explained 45.3% of the variance in students' satisfaction ($R^2 = 0.453$, $F = 24.527$, $p < 0.001$). Among the six PVT requirements, representation ($\beta = 0.550$, $p < 0.001$) and reach ($\beta = 0.207$, $p = 0.002$) were significant predictors of students' satisfaction with online Mathematics learning.

while sensory requirements, relationship requirements, synchronism requirements, and monitoring were not statistically significant predictors. These findings indicate that representation and reach are particularly relevant to students' satisfaction with online Mathematics learning. This study contributes to a better understanding of the application of PVT requirements in evaluating online Mathematics learning environments in higher education.

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Keyword:

Online Learning, Process Virtualization Theory, Reach, Representation, Students' Satisfaction



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Introduction

The growing use of digital technologies has transformed the way teaching and learning are delivered in higher education. Online learning enables students to participate in academic activities, access learning resources, and communicate with instructors and peers beyond the boundaries of the traditional classroom. Although the adoption of online learning increased substantially during the COVID-19 pandemic, sustaining its use has become an important consideration for higher education institutions. However, providing online learning does not necessarily ensure that students will have positive experiences or remain satisfied with the learning environment. Student satisfaction reflects students' overall evaluation of their learning experience and is influenced by technological, instructional, and interaction factors. Previous research has demonstrated that satisfaction is an important factor in students' experiences with online learning and may influence their willingness to continue using online learning platforms. For example, Lee (2010) found that satisfaction significantly influenced users' intention to continue using e-learning, while Daghan and Akkoyunlu (2016) identified satisfaction as an important predictor of students continued use of online learning. More recently, Mansor et al. (2025) revealed that information quality, system quality, service quality, perceived usefulness, perceived ease of use, and cognitive absorption were significantly associated with student satisfaction with online learning platforms in a Malaysian higher education institution. Similarly, Khong et al. (2024) highlighted the importance of institutional support and social competencies in shaping online learning satisfaction among students in Malaysian private higher education institutions. These findings indicate the importance of understanding the factors that shape students' satisfaction with online learning.

The quality of students' experiences in online learning may depend on how effectively online environments reproduce important characteristics of traditional face to face learning. Process Virtualization Theory (PVT), introduced by Overby (2008), provides a useful theoretical perspective for examining whether processes that traditionally occur in physical environments

can be performed effectively through information technology. PVT identifies several requirements related to the virtualization of a process, including sensory requirements, relationship requirements, synchronism requirements, representation, reach, and monitoring. These requirements are particularly relevant to online learning because students may need visual and interactive experiences, communication with instructors and peers, timely interaction, accessible learning resources, and appropriate monitoring of their learning activities. Alarabiat et al. (2023) applied PVT to online learning context and found that several virtualization requirements significantly influenced students' satisfaction. Their findings demonstrate that PVT can provide a valuable framework for understanding students' perceptions of virtual learning environments. However, previous research on online learning satisfaction has largely focused on technological, instructional, and institutional factors, with less attention given to how the requirements for virtualizing processes traditionally carried out in physical learning environments are related to student satisfaction. PVT is therefore needed to provide a process-based perspective for understanding how specific characteristics of face-to-face learning can be effectively reproduced in online environments.

Therefore, this study aims to examine the relationships between sensory requirements, relationship requirements, synchronism requirements, representation, reach, monitoring, and students' satisfaction with online Mathematics learning. Specifically, the study seeks to identify which PVT requirements are significantly associated with students' satisfaction and to provide a better understanding of the characteristics that make online learning environments more acceptable and effective. The study extends previous research on process virtualization in online learning by examining students' satisfaction within the Malaysian higher education context, particularly among undergraduate students enrolled in Calculus courses. By applying PVT to this context, the study provides empirical evidence on the relationships between PVT requirements and students' satisfaction with online Mathematics learning. The findings are expected to contribute to the existing PVT literature and provide practical implications for higher education institutions and educators in designing and improving online learning environments that better address students' learning needs.

Literature Review

Sensory Requirements

Sensory requirements refer to the extent to which students require sensory experiences normally available in a physical environment, including visual, auditory, and interactive experiences (Overby, 2008). In online learning, students may rely on videos, animations, audio explanations, graphical representations, and interactive materials to compensate for the absence of face-to-face sensory experiences. From the perspective of PVT, higher sensory requirements may make a process more difficult to conduct virtually because digital environments may not fully reproduce physical sensory experiences. Research by Alarabiat et al. (2023) found that sensory requirements significantly influenced students' satisfaction with online learning, highlighting the importance of sensory experiences in virtual education. Similarly, Simonova et al. (2023) emphasized the importance of varied digital content and effective content delivery in supporting students' online learning experiences. Therefore, online learning interfaces that effectively accommodate students' sensory requirements through appropriate multimedia and interactive features may provide a more engaging learning environment and consequently enhance students' satisfaction.

Relationship Requirements

Relationship requirements refer to students perceived need to interact, communicate, socialize, and establish relationships with other participants in a learning process (Overby, 2008). In online learning, these requirements may involve interaction with instructors and peers, collaborative learning, communication, and the development of social connections. Since face-to-face interaction is limited in virtual environments, technological platforms need to provide appropriate communication and collaboration features. According to Martin and Bolliger (2022), interaction, communication, social presence, collaboration, and connectedness are important factors associated with online learner satisfaction, based on a systematic review of 98 studies. Kuo et al. (2014) demonstrated that learner instructor and learner content interactions significantly contributed to students' satisfaction with online education. Richardson et al. (2017) further demonstrated that social presence was positively associated with student satisfaction in online learning environments. In addition, Alarabiat et al. (2023) reported that relationship requirements significantly influenced students' satisfaction with online learning. These findings indicate that meaningful communication and social interaction remain important in virtual learning environments. Therefore, online learning interfaces that facilitate effective interaction and relationship development between students and instructors are expected to contribute positively to students' satisfaction with online learning.

Synchronism Requirements

Synchronism requirements refer to the extent to which participants need to communicate and interact with one another in real time or with minimal delay (Overby, 2008). In online learning setting, synchronism communication may take place through live lectures, video conferencing, real time discussions, and prompt feedback. While synchronous interaction can provide opportunities for immediate clarification and communication, it may also require more technological resources and greater coordination. Martin et al. (2021) found that synchronous online learning was associated with positive cognitive and affective outcomes when compared with asynchronous learning, indicating its potential role in supporting students' learning experiences. In a similar context, research by Caskurlu et al. (2020) indicated that teaching presence was positively associated with student satisfaction in online learning. According to Fujii et al. (2022), students in synchronous online courses reported higher levels of satisfaction than those in asynchronous courses, highlighting the potential benefits of real time interaction for students' online learning experiences. However, Alarabiat et al. (2023) found no statistically significant relationship between synchronism requirements and students' satisfaction with online learning. This finding implies that students may not necessarily require real time interaction to achieve satisfactory online learning experiences. Therefore, the influence of synchronism requirements on satisfaction may depend on course characteristics, students' learning needs, and the availability of effective asynchronous alternatives.

Representation

Representation refers to the capability of information technology to display or reproduce aspects of a physical process within a virtual environment (Overby, 2008). In online learning, this requirement can be observed in the use of text, images, diagrams, mathematical notation, videos, animations, and simulations. This aspect is particularly relevant to Calculus courses because many mathematical concepts are difficult to visualize and may be easier to understand when supported by graphical and visual illustrations. Waheed et al. (2016) found that aspects

of knowledge quality, including accessibility and representational features of e-learning content, were associated with student satisfaction. Similarly, Simonova et al. (2023) emphasized the importance of effective digital content delivery in online and blended learning environments. Mahir et al. (2021) noted that students' satisfaction with mathematics education was related to the learning materials and educational services available through an open education system, highlighting the importance of appropriate digital and instructional resources in mathematics learning. Furthermore, Alarabiat et al. (2023) reported that representation for sensory and relationship requirements significantly contributed to students' satisfaction with online learning. These findings indicate that how learning materials are represented within an online environment can influence students' perceptions of the learning experience. Therefore, clear, accessible, and effective representation of mathematical content through an online learning interface is expected to contribute positively to students' satisfaction.

Reach

Reach refers to the capability of information technology to enable participation in a process across different locations and times (Overby, 2008). In online learning, reach allows students to access learning materials, participate in activities, communicate with instructors, and complete coursework regardless of their physical location. This capability provides flexibility and may reduce geographical and time related limitations in learning. Martin and Bolliger (2022), in a systematic review of online learner satisfaction, identified technology access and course delivery as important factors associated with students' satisfaction. Rahman et al. (2024) noted that the quality and accessibility of e-learning platforms play a substantial role in sustaining student satisfaction within Malaysian public universities. A study by Turan et al. (2022) found flexibility was a significant factor affecting students' satisfaction with distance education, highlighting the importance of being able to learn across different times and locations. Similarly, Suryani and Sugianingrat (2021) showed a relationship between e-learning flexibility and student satisfaction, suggesting that convenient learning opportunities in terms of time and place can contribute to positive online learning experiences. Alarabiat et al. (2023) indicated that reach significantly influenced students' satisfaction with online learning. These findings demonstrate that convenient and flexible access to learning resources is an important characteristic of online learning environments.

Monitoring

Monitoring refers to the capability of information technology to provide information about participants and track activities within a virtual process (Overby, 2008). In online learning, monitoring may include tracking attendance, participation, assignment submissions, assessment performance, and learning progress. Such functionality allows instructors to identify students who may require additional support and enables students to monitor their own learning performance. Viberg et al. (2019) showed that learning analytics can provide information about students' online learning activities and support educational decision making. According to Ameloot et al. (2024), teachers' use of learning analytics to adapt the learning environment positively influenced students' satisfaction. Ofoeda et al. (2018) also identified monitoring capability as an important information technology characteristic that facilitates the virtualization of processes.

Students' Satisfaction

Student satisfaction refers to the extent to which students perceive that their needs and expectations have been fulfilled through their learning experience. In online education, satisfaction is a multidimensional construct that includes students' perceptions of the learner, instructor, course, program, and organizational aspects of the online learning environment (Martin & Bolliger, 2022). Student satisfaction is an important outcome because it is related to students' engagement, motivation, academic success, persistence, and retention in online learning. Kim and Park (2023) found that instructional support, technology acceptance, and perceived presence were associated with students' satisfaction with online learning. Chen and Mohammed (2024) also identified technology, course design, interaction, and learner support as important factors influencing student satisfaction in online distance learning. Alarabiat et al. (2023) applied PVT in the context of online learning and examined the factors associated with students' satisfaction and intention to continue using online learning. The findings showed that sensory requirements, relationship requirements, reach, representation for sensory requirements, and representation for relationship requirements were significantly associated with students' satisfaction. However, synchronism requirements and identification and control requirements were not significantly associated with satisfaction. These findings indicate that students' satisfaction can be related to different aspects of the online learning environment. Therefore, satisfaction is an appropriate dependent variable for evaluating students' perceptions of online learning.

Conceptual Framework

The conceptual framework illustrates the relationships between six PVT requirements and students' satisfaction with online Mathematics learning. The independent variables comprise sensory requirements, relationship requirements, synchronism requirements, representation, reach, and monitoring, while students' satisfaction with online Mathematics learning serves as the dependent variable. Figure 1 presents the proposed conceptual framework and hypothesised relationships.

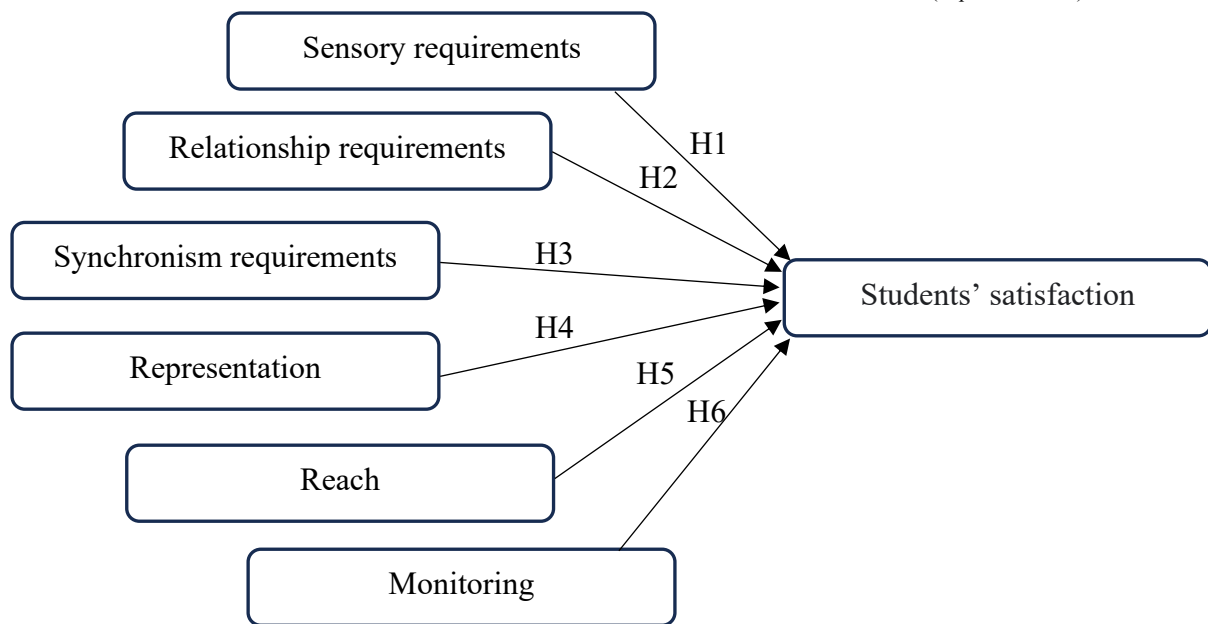


Figure 1: Conceptual Framework

The Present Study

This study examines the relationships between the six PVT requirements and students' satisfaction with online Mathematics learning. Accordingly, six research questions were formulated to guide the study:

- RQ1 : Is there a statistically significant relationship between sensory requirements and students' satisfaction with online Mathematics learning?
- RQ2 : Is there a statistically significant relationship between relationship requirements and students' satisfaction with online Mathematics learning?
- RQ3 : Is there a statistically significant relationship between synchronism requirements and students' satisfaction with online Mathematics learning?
- RQ4 : Is there a statistically significant relationship between representation and students' satisfaction with online Mathematics learning?
- RQ5 : Is there a statistically significant relationship between reach and students' satisfaction with online Mathematics learning?
- RQ6 : Is there a statistically significant relationship between monitoring and students' satisfaction with online Mathematics learning?

Based on the conceptual framework and previous literature, six hypotheses were developed to examine the relationships between the six PVT requirements and students' satisfaction with online Mathematics learning. The proposed hypotheses are as follows:

- H1 : Sensory requirements have a statistically significant relationship with students' satisfaction with online Mathematics learning.
- H2 : Relationship requirements have a statistically significant relationship with students' satisfaction with online Mathematics learning.
- H3 : Synchronism requirements have a statistically significant relationship with students' satisfaction with online Mathematics learning.

- H4 : Representation has a statistically significant relationship with students' satisfaction with online Mathematics learning.
- H5 : Reach has a statistically significant relationship with students' satisfaction with online Mathematics learning.
- H6 : Monitoring has a statistically significant relationship with students' satisfaction with online Mathematics learning.

Methodology

Sample and Procedure

Data were collected using a structured online questionnaire administered through Google Forms and analysed using SPSS. The study involved undergraduate students enrolled in a Calculus course at a Malaysian public university. A total of 185 valid responses were obtained from students who had experience using online learning for their Calculus course and were used for data analysis. The collected data were analysed to examine the relationship between the six PVT requirements on students' satisfaction with online Mathematics learning.

Instruments

The questionnaire used in this study was adapted from Alarabiat et al. (2024), which examined PVT in the context of online learning. The questionnaire consisted of two sections. The first section collected demographic information from the respondents, including gender, place of residence, home Wi Fi internet access, and devices used to access online learning. The second section comprised 33 items measuring seven variables, namely sensory requirements, relationship requirements, synchronism requirements, representation, reach, monitoring and students' satisfaction with Mathematics online learning. All items were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

The six PVT requirements were included to reflect different aspects of students' online learning experiences. Sensory requirements relate to students' need for sensory experiences associated with the physical learning environment, such as seeing and hearing lecturers and classmates. Relationship requirements refer to students' need for social interaction and relationships with lecturers and classmates. Synchronism requirements concern the need to communicate and interact in real time or with minimal delay, including attending classes at the appropriate time and receiving timely learning activities. Representation refers to the capability of information technology to present or reproduce elements of a physical learning process within a virtual environment, such as through text, images, diagrams, mathematical notation, videos, animations, and simulations. Reach relates to students' ability to access and attend online lectures regardless of location or certain physical conditions. Monitoring concerns students' experiences with online attendance, activity tracking, and webcam use during online classes.

Data Analysis

The collected data were analysed using SPSS. Prior to the main analysis, the reliability of the instrument was assessed to determine the internal consistency of the measurement items using Cronbach's alpha. Descriptive statistics, including frequency and percentage were used to summarise the respondents' demographic characteristics. Pearson correlation analysis was conducted to examine the relationships between the independent variables and the dependent

variable. Subsequently, multiple regression analysis was conducted to examine the relationships between the six PVT requirements, namely sensory requirements, relationship requirements, synchronism requirements, representation, reach, and monitoring, and students' satisfaction with online Mathematics learning.

Analysis and Findings

The results of the SPSS analysis based on 185 respondents are presented and discussed, including reliability analysis, descriptive statistics, correlation analysis, and multiple linear regression analysis.

Reliability Analysis

Reliability was evaluated by assessing the internal consistency of the items representing each variable using Cronbach's alpha. Table 1 presents the Cronbach's alpha values used to assess the reliability of the measurement instrument. The internal consistency of all variables exceeded the recommended benchmark of 0.70, with values of 0.925, 0.875, 0.921, 0.828, 0.944, 0.894, and 0.800 for students' satisfaction, sensory requirements, relationship requirements, synchronism requirements, representation, reach, and monitoring, respectively. The Cronbach's alpha value for all 33 items combined was 0.914. These results indicate that all variables demonstrated high internal consistency and that the measurement instrument was reliable.

Table 1: Reliability Analysis

Variables	No of Items	Cronbach's alpha
Students' satisfaction	5	0.925
Sensory requirements	5	0.875
Relationship requirements	5	0.921
Synchronism requirements	4	0.828
Representation	8	0.944
Reach	3	0.894
Monitoring	3	0.800
All items	33	0.914

Descriptive Statistics

Table 2 indicates the demographic characteristics of the 185 undergraduate students enrolled in Calculus courses. The majority of respondents were female (73.0%, $n = 135$), while male participants represented 27.0% ($n = 50$). Regarding their place of residence, the majority of students lived in city or urban areas (69.2%, $n = 128$), whereas 30.81% ($n = 57$) lived in town or rural areas. Most respondents had home Wi-Fi internet access (84.86%, $n = 157$). In terms of devices used for online learning, laptops were the most commonly used (58.38%, $n = 108$), followed by tablets (26.49%, $n = 49$), mobile phones (14.05%, $n = 26$), and desktop computers (1.08%, $n = 2$). Overall, the findings show that the students were predominantly female, urban residents, and had access to home Wi-Fi and digital devices for online learning.

Table 2: Respondent Demographic Profile

Variables	Frequency (n)	Percentage (%)
Gender		
Male	50	27
Female	135	73
Place of residence		
City or Urban areas	128	69.2
Town, Village (Rural areas)	57	30.81
Home Wi-Fi Internet access		
Yes	157	84.86
No	28	15.14
Device used for access online learning		
Mobile phone	26	14.05
Laptop	108	58.38
Tablet	49	26.49
Desktop computer	2	1.08

Table 3 presents the mean (M) and standard deviation (SD) for each study variables. Among the independent variables, reach recorded the highest mean score of 4.30 (SD = 0.65), followed by synchronism requirements (M = 4.20, SD = 0.64), relationship requirements (M = 4.13, SD = 0.63), sensory requirements (M = 4.10, SD = 0.64), representation (M = 3.56, SD = 0.81), and monitoring (M = 2.85, SD = 0.85). Overall, students' satisfaction recorded a mean score of 3.77 (SD = 0.79). These findings indicate that reach had the highest mean score among the independent variables, while monitoring had the lowest mean score.

Table 3: Mean of each Group Variable

Variables	Mean (M)	Standard Deviation (SD)
Students' satisfaction	3.77	0.79
Sensory requirements	4.10	0.64
Relationship requirements	4.13	0.63
Synchronism requirements	4.20	0.64
Representation	3.56	0.81
Reach	4.30	0.65
Monitoring	2.85	0.85

Correlation Analysis

Table 4 presents the Pearson correlation analysis examining the relationships between the PVT requirements and students' satisfaction with online Mathematics learning. The results indicate that representation had a strong positive and statistically significant relationship with students' satisfaction with online Mathematics learning ($r = 0.633$, $p < 0.01$), while reach showed a moderate positive and statistically significant relationship ($r = 0.460$, $p < 0.01$). Synchronism requirements ($r = 0.186$, $p < 0.05$), relationship requirements ($r = 0.164$, $p < 0.05$), and sensory requirements ($r = 0.145$, $p < 0.05$) demonstrated weak but statistically significant positive relationships with students' satisfaction. In contrast, monitoring showed a weak negative and not statistically significant relationship with students' satisfaction ($r = -0.127$, $p > 0.05$). Overall, representation and reach demonstrated the strongest positive relationships with

students' satisfaction with online Mathematics learning, whereas monitoring did not show a statistically significant relationship.

Table 4: Correlations Result

Variables	Students' satisfaction
Students' satisfaction	1
Sensory requirements	0.145*
Relationship requirements	0.164*
Synchronism requirements	0.186*
Representation	0.633**
Reach	0.460**
Monitoring	-0.127

*Correlation is significant at the 0.05 level (2-tailed)

**correlation is significant at the 0.01 level (2-tailed)

Regression Analysis

Table 5 indicates that the R^2 value is 0.453, showing that 45.3% of the variance in students' satisfaction can be explained by the six PVT requirements. Meanwhile, the remaining 54.7% is explained by other factors not included in this study.

Table 5: Model Summary

Model	R	R^2	Adjusted R^2
1	0.673	0.453	0.434

Table 6 presents the results of the overall significance test for the multiple regression model, with an F-statistic of 24.527 ($p < 0.001$). The significant F-test indicates that the regression model is statistically significant, suggesting that the six PVT requirements collectively provide significant predictive value for students' satisfaction with online Mathematics learning.

Table 6: ANOVA

Model	Sum of squares	df	Mean square	F	Sig.
Regression	51.724	6	8.621	24.527	<0.001
Residual	62.562	178	0.351		
Total	114.285	184			

Dependent variable: Students' satisfaction.

Predictors: (Constant), Sensory requirements, Relationship requirements, Synchronism requirements, Representation, Reach, Monitoring.

Table 7 presents the results of the multiple regression analysis examining the relationships between the six PVT requirements and students' satisfaction with online Mathematics learning. Representation ($B = 0.533$, $\beta = 0.550$, $t = 8.760$, $p < 0.001$) and reach ($B = 0.249$, $\beta = 0.207$, $t = 3.141$, $p = 0.002$) were statistically significant predictors of students' satisfaction. Representation recorded the highest standardized beta coefficient ($\beta = 0.550$), indicating that it was the strongest significant predictor of students' satisfaction among the six PVT requirements. In contrast, sensory requirements ($p = 0.409$), relationship requirements ($p = 0.090$), synchronism requirements ($p = 0.163$), and monitoring ($p = 0.566$) were not statistically

significant predictors of students' satisfaction in the multivariate model. The resulting regression equation for students' satisfaction with online Mathematics learning is: Students' satisfaction = $0.765 + 0.082(\text{sensory requirements}) - 0.176(\text{relationship requirements}) + 0.124(\text{synchronism requirements}) + 0.533(\text{representation}) + 0.249(\text{reach}) - 0.031(\text{monitoring})$.

Table 7: Coefficients

Model	Unstandardized Coefficient		Standardized Coefficients (β)	t-value	Sig
	B	Std. Error			
(constant)	0.765	0.447	-	1.713	0.089
Sensory requirements	0.082	0.099	0.066	0.827	0.409
Relationship requirements	-0.176	0.103	-0.142	-1.704	0.090
Synchronism requirements	0.124	0.088	0.100	1.401	0.163
Representation	0.533	0.061	0.550	8.760	<0.001
Reach	0.249	0.079	0.207	3.141	0.002
Monitoring	-0.031	0.054	-0.033	-0.575	0.566

Dependent variable: Students' Satisfaction.

Confirmation of Hypothesis

Table 8 summarises the results of hypothesis testing obtained from the multiple regression analysis at a 0.05 level of significance. The hypothesis decisions were based on the significance of the individual predictors in the multivariate regression model. The results show that H4 and H5 were supported, as representation ($p < 0.001$) and reach ($p = 0.002$) were statistically significant predictors of students' satisfaction with online Mathematics learning. In contrast, H1, H2, H3 and H6 were not supported. Sensory requirements ($p = 0.409$), relationship requirements ($p = 0.090$), synchronism requirements ($p = 0.163$) and monitoring ($p = 0.566$) did not make statistically significant unique contributions to students' satisfaction in the multiple regression model. Pearson correlation analysis showed significant bivariate relationships for sensory, relationship and synchronism requirements, whereas the simultaneous analysis of the six PVT requirements in the multiple regression model showed that these three requirements were not statistically significant predictors of students' satisfaction. This difference suggests that their bivariate associations with students' satisfaction may not remain significant after controlling for the other PVT requirements.

Table 8: Summarise Hypothesis Result

Hypotheses	Decision
H1 : Sensory requirements have a statistically significant relationship with students' satisfaction with online Mathematics learning.	Not supported
H2 : Relationship requirements have a statistically significant relationship with students' satisfaction with online Mathematics learning.	Not supported
H3 : Synchronism requirements have a statistically significant relationship with students' satisfaction with online Mathematics learning.	Not supported
H4 : Representation has a statistically significant relationship with students' satisfaction with online Mathematics learning.	Supported

H5	: Reach has a statistically significant relationship with students' satisfaction with online Mathematics learning.	Supported
H6	: Monitoring has a statistically significant relationship with students' satisfaction with online Mathematics learning.	Not supported

Conclusion

This study applied PVT to examine the factors associated with students' satisfaction with online Mathematics learning at the higher education level. Results showed that the regression model was statistically significant and explained 45.3% of the variance in students' satisfaction ($R^2 = 0.453$, $F = 24.527$, $p < 0.001$). Among the six PVT requirements, representation emerged as the strongest significant predictor of students' satisfaction ($\beta = 0.550$, $p < 0.001$), followed by reach ($\beta = 0.207$, $p = 0.002$). In contrast, sensory requirements, relationship requirements, synchronism requirements, and monitoring were not statistically significant predictors in the multivariate model. The findings indicate that effective representation of mathematical content through clear visual and auditory delivery, together with flexible and location independent access to online learning platforms, is significantly associated with students' satisfaction with online Mathematics learning. Therefore, higher education institutions and educators should consider improving the quality of digital content presentation and ensuring accessible and flexible learning platforms to support positive online learning experiences.

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- Declaration on the Use of Artificial Intelligence (AI)** “The author(s) declare that generative AI or AI-assisted technologies were used during the preparation of this manuscript. The following tool was used: ChatGPT. The tool was used for language editing, grammar improvement, and refinement of the manuscript. All AI-assisted content was reviewed and verified by the author(s), who take full responsibility for the accuracy, originality, integrity, and final content of the manuscript.”
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