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Exploring the Effects of Online Learning Complications on Mathematics Achievement

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The aim of the research was to examine different complications of learning mathematics online and their effects on students' academic performances. A cross-sectional survey design was employed among 2311 students from the school to university levels in Nepal. Hierarchical linear regression and machine learning were major statistical techniques used in the research. The findings indicated that access to and cost of digital devices, training on digital skills, assignment submission skills, digital literacy, and a separate study room at home were major complications for students in learning mathematics online. Additionally, these complications to learning mathematics online negatively affect students' academic performance. This research gives new insights into the complications of online learning and its effect on learners' performance in mathematics as well.

Keywords: achievement, complications, internet, mathematics, virtual learning

INTRODUCTION

Virtual learning is a demand of the 21st century. Several models have been developed and implemented for online mathematics learning with appropriate strategies based on the underlined theories (Møgelvang & Nyléhn, 2023; Adedoyin & Soykan, 2020). However, inaccessibility, poor connectivity, and inappropriate use of digital resources are identified as the major challenges of virtual learning, especially in developing economies like Nepal (Adhikari et al., 2023; Joshi, Adhikari, Khanal, et al., 2023; Joshi,

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Chapai, & Khanal, 2023; Joshi, Khanal, & Adhikari, 2023; Joshi, Khanal, & Dhakal, 2023; Hillier, 2018; Thapa & Sein, 2018; Zhou et al., 2011) and parents' digital literacy, occupation, and socioeconomic status also affect the availability and use of digital technology at home for learning (Adedoyin & Soykan, 2020; Papadakis et al., 2019; Tondeur et al., 2011). The current study focuses on the problems, difficulties, and challenges of students while taking mathematics classes online as complications of learners in Learning Mathematics (CLLM) through the virtual mode of instruction (VMI).

Access to digital resources is necessary for online learning (Khanal et al., 2022). However, access to technology or resources is not enough for ensuring the learning in schools and at home for teaching-learning activities, and how they use them also matters (Sailer et al., 2021). In this context, on the one hand, the effective use of online and digital tools in the classroom depends on teachers' competency and readiness; connectivity and access, as well as engagement, are crucial components (Kong et al., 2014; Nicholas & Fletcher, 2017; Sailer et al., 2021). On the other hand, the online resource usage habits of the teachers in virtual instructional practices depend on the nature of the online instructional design (Recker et al., 2007; Khadka et al., 2022) and the lack of digital competency of students and teachers in using digital resources (Adedoyin & Soykan, 2020). Further, parents' and teachers' perceptions of technology and digital media impact the development of a digital-friendly environment at home and school (Ihmeideh & Alkhawaldeh, 2017). Open access to knowledge and academic resources through digitalization is inevitable for online mathematics learning, but it is not enough (Ahmed, 2007). Hence study is needed to explore the complications students face while studying online in general, and mathematics online particular.

The primary objective of this research is to investigate the effect of challenges of learners during online learning on academic performance in mathematics when instructed through virtual teaching methods. While the prior research we examined and outlined earlier highlighted issues and difficulties with online mathematics instruction, it is important to note that the impact of (1) infrastructure and resources, (2) home environment, (3) policy and planning, and (4) skills and training in the context of online computer-assisted mathematics learning have yet to be fully elucidated. Therefore, this study is focused on the following research questions.

1. What are the complications of learners in learning mathematics (CLLM) online?
2. How do the complications of learners in learning mathematics online affect students' performance?

Mathematics Online Learning: Access, Use and Challenges

After the outbreak of Corona Virus, governments of developing countries, including Nepal, quickly declared that schools and universities would move classes online to contain the virus, learning continued virtually despite several challenges (Mishra et al., 2020). Mostly, these countries faced problems running online classes due to a lack of budget, planning, preparation, management, technical infrastructure, institutional readiness, quality of online course content, digital awareness, and digital competency

among teachers and students (Ahmad et al., 2023; Joshi et al., 2023; Sahoo & Rana, 2023). It was essential for the governments to establish reliable communication channels and access to digital resources for students and teachers (Mishra et al., 2020). Such efforts were severely impacted by the lack of economic resources to develop uninterrupted internet connections for mathematics learning online. Studies found that families with better socioeconomic status can provide more digital resources to their children than those from low socioeconomic backgrounds (Jæger & Blaabæk, 2020). This issue was related to digital equity in establishing a cross-cultural connection between students, teachers, and schools (Resta & Laferrière, 2015).

In an increasingly digitized economy, an individual's quality of life depends on his/her access to digital technologies (Lu, 2001). The development of information and communication technology (ICT) helps to minimize the socioeconomic gap perpetuated by the digital divide within and across different countries (Doong & Ho, 2012). For instance, the income and education of parents can affect children's access to the internet (Zhou et al., 2011), and the use of updated and sophisticated digital devices (Adedoyin & Soykan, 2020) enhances virtual learning. Moreover, one-size-fits-all policies in the use and access to ICT in teaching and learning cannot minimize the digital divide issue (Lembani et al., 2020). In a study by Rashid (2016) in five developing countries (Bangladesh, Ghana, Chile, Brazil, and the Philippines), education was one of the strongest determinants of ICT access. The study also confirmed that social inequalities in a country directly correlate with the digital divide (Laeeq Khan et al., 2020).

The expansion of online education during the COVID-19 pandemic has revealed a significant gap in the availability of clear and comprehensive guidelines for the development and utilization of digital resources. This lack of proper ICT training for mathematics teacher is a significant obstacle to ensuring student’s access to quality educational materials (Beyene et al., 2020, UNESCO, UNICEF & The World Bank, 2021). Describing the given content matters by using only the PowerPoint presentation is not sufficient in learning mathematics. PowerPoint may be a starting point but teachers should use interactive elements to engage students in the solution of mathematical problems, visualizing applications to visualize the relations between mathematical concepts and supportive resources for independent learning (Ali et al., 2023). Only the appropriate integration of supportive digital tools in learning mathematics may facilitate the relationship between mathematical conception and students' experiences (Zeynivandnezhad et al., 2020). For this, digital and graphical tools support visualizing an accurate object and sketching the solution to a problem (Hoyles, 2018). However, selecting and using appropriate online learning tools for mathematics is paramount because any learning tools, such as recorded learning videos, may develop surface approaches to learning mathematics, harming academic performance (Trenholm et al., 2019). The design of such tools and resources for online mathematics learning should promote academic performance and reduce mathematical anxiety (Adu et al., 2017). Parent's beliefs and experiences in using digital media are interlinked with the children's self-efficacy in digital media (Hammer et al., 2021).

Several components are vital in making mathematics learning effective in a virtual environment. Among them, digital literacy comes first and foremost and is the primary

determinant of digital inequalities (Nishijima et al., 2017). Digital inequality refers to disparities in digital access. Access to digital technologies varies in gender, age, and education (Lopez-Sintas et al., 2020). Moreover, students with greater cultural capital are more likely to gain ICT competency and achieve better mathematics learning results (Scherer & Siddiq, 2019; Yuen et al., 2018). Mothers' education significantly impacts students' mathematics achievement more than their income and occupation (Qi & Wu, 2020).

A recent study in Chile found that higher financial and cultural resources would lead to higher parental expectations and better student academic achievement (Hascoët et al., 2021). Besides these, parents' beliefs and expectations can also be detrimental to children's academic attainment (Ndijuye, 2020). For example, parents' involvement (Jay et al., 2018), professional situation (Tondeur et al., 2011), and parenting styles (Yang & Zhao, 2020) have a significant impact on student's academic performance (Schneider et al., 2018). Parents with an authoritative parenting style positively influence students' digital skills and deal with other challenges in learning online (Rodríguez-de-Dios et al., 2018). Parents' education also influences students' adaptation to rapid technological progress (Papadakis et al., 2019). Most of the research studies we reviewed and noted above focus on the face-to-face mode of instruction, however, few studies regarding the online learning are done in the western contexts. The case of developing countries like Nepal would be different from developed countries cases. So, this study would might be useful to bring some evidence-based information regarding the complications that students are facing in learning mathematics online, particularly, in the developing countries.

Conceptual Framework of the Study

A review of the literature shows that digital infrastructure and devices (Palvia et al., 2018), trained teachers (Kisanga & Ireson, 2015), availability of online resources, and technical support for teachers and students (Dhawan, 2020) are major factors affecting online learning (Zalat et al., 2021). Baticulon et al. (2021) and Jusas et al. (2021) suggested that using digital tools by students is also important for online learning. Dayagbil et al. (2021) mentioned that assignment submission is an issue in online learning because of access to the Internet. In contrast, Khan et al. (2021) considered that scheduling, technical skills, a separate room for study, digital resources, and motivation are additional issues in online learning. Shrestha and Gnawali (2021) reported that policy provision is an issue in online learning. Barrot et al. (2021) also reported these issues in seven dimensions, and Jaashan (2020) under eight dimensions. The conceptual framework (Figure 1) was made in light of the above theoretical ideas.

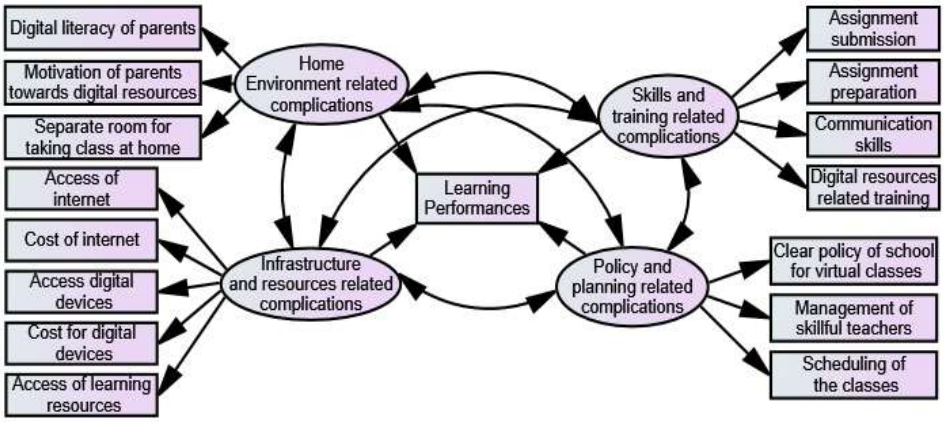

Figure 1
Conceptual Framework

METHOD

A cross-sectional survey design was employed in this research (Cohen et al., 2007; Creswell, 2014). A total of 2,311 students from K–12 to university level (total 47 institutions) in Nepal participated in this research. Forty students who studied MPhil at Nepal Open University (NOU) were employed to administer the survey for data collection. A convenience sampling technique was used to select the 47 institutions, whereas a random sampling technique was followed to select students. The data were collected from the students at the basic (class eight), secondary (class ten), and university (bachelor's 1st year) levels. Instructions for preparing and administering the questionnaire were given to 40 scholars before they departed for data collection. The data were collected by taking informed consent of the participants. The informed consent-related information was clearly mentioned in the survey instruments. The participant consent consists purpose of the research, study level of participants (school to university can participate in the survey), voluntary participation in the survey, right to not participate and stop their participation at any time in the research, and approximate time to participate. Additionally, the confidentiality of personal information and data and the application of information for research purposes were clearly mentioned in the survey instrument.

Research Instrument

A self-constructed tool was employed in the research. The researchers assembled the tool by amalgamating insights from the literature on virtual learning, their own practical experiences, and the essential requirements of online learners. The researchers constructed the instrument based on the available literature on virtual learning, the researchers' personal experiences, and the necessary demands of learners for online learning. The nature of the items was a Likert scale from strongly agree to strongly disagree; they were rated from 1 to 5, respectively. Before data collection, the reliability of the instrument was ensured by a pilot study among 140 students in Kathmandu

district. The reliability of the instrument was calculated by Cronbach's Alpha method and found to be 0.77, which is acceptable for research (Coolican, 2013; Verma & Abdel-Salam, 2019). The validity was ensured by the face validity technique (Garson, 2013) by sharing instruments with six experts from the fields of education, mathematics, and computer science. Additionally, the item-total correlation was calculated to ensure validity by the correlation method, and the correlation value was found to be significantly positive in each item (Table 2). The instrument consists of fifteen items related to the CLLM through VMI under four categories: (1) infrastructure and resources; (2) skills and training; (3) policy and planning; and (4) home environment. The details of the study variables are presented in the Figure 1.

Variables Used in the Research

In this research, the CLLM through VMI is considered independent and mathematics performance is a dependent variable. Mathematics performance indicates achievement scores in mathematics. Mathematics achievement score was taken from the respective institution of the students because every institution has the provision of formative assessment (40%) and written examination (60%), which is an authorized and verified system of evaluation by different level of government and universities. All institutions have the rule and practice of following Bloom Taxonomy during questionnaire design; hence researchers assumed that the achievement score was valid and reliable.

Data Analysis Techniques

Descriptive and inferential statistics were used for data analysis. Mean, and standard deviation (SD) were used to show the status of CLLM online and mathematics achievement under descriptive statistics. The one-sample t-test was used to calculate the significant level of complications by assuming three as the population mean (Joshi et al., 2022; Joshi, Adhikari, Khanal, et al., 2023). Additionally, standardized residuals were checked before applying inferential statistics to evaluate for assumptions of normality, homoscedasticity, linearity, independence of errors, and absence of outliers (Field, 2018; Tzagkarakis & Fidell, 2007). The correlation diagram was used to show the relationship between all CCL through VMI related items used in the research. For examining the effect of CLLM online on achievement, hierarchical linear regression was performed by loading skill and training-related problems, home environment-related problems, policy and planning-related problems, and infrastructure and resources-related problems in model one to four respectively was employed. Moreover, regularized linear regression model under machine learning was used to find the item wise effect on mathematics achievement and test the accuracy of the data.

FINDINGS

Status of CLLM through VMI

Table 1 shows the access and cost of digital devices under infrastructure and resources-related problems, training on the use of digital resources and assignment submission under skills and training, scheduling the classes and policy of the institution for a virtual class, and digital literacy of the parents and a separate room for taking a class under home environment found to be major complications as compared to other.

Communication skills and management of skilful teachers were found to be minor complications based on overall items. Furthermore, all complications related to skills and training were significantly high except for the lack of communication skills because it had significantly low results. Similarly, the problems were found to be significantly high in HEP1 and HEP3; however, the result is significantly low in HEP2 under home environment-related problems. Furthermore, the level of problems was found to be significantly low in PPP2, IRP2, and IRP5. In contrast, the level of problems is significantly high in other cases under policy and planning as well as infrastructure and resources-related problems except as PPP1. In comparison to dimensions, infrastructure and resources, policy and planning, and home environment-related CLLM through VMI were minor compared to skills and training-related problems; however, only the level of skills and training-related problems is significantly high. The mathematics achievement was found to be significantly high (Mean=57.25, SD=17.14) because of having a mean greater than the assumed population mean (50).

Table 1
Item and dimension-wise mean and standard deviation of CLLM through VMI (n=2311)

Items with dimensions	Mean	SD	t-value	ITC
Skill and training-related problems (STP)	3.05	0.75	3.21**	
Lack of digital resources-related training (STP1)	3.24	1.31	8.66**	.51
Lack of Communication Skills (STP2)	2.75	1.24	-9.63**	.20
Difficulties in Assignment Preparation (STP3)	3.10	1.27	3.76**	.49
Problem in Assignment Submission (STP4)	3.11	1.26	4.35**	.52
Home environment-related problems (HEP)	3.02	0.75	1.49	
Lack of digital literacy of parents (HEP1)	3.18	1.32	6.42**	.46
Lack of parent's motivation toward the use of digital resources (HEP2)	2.82	1.34	-6.59**	.14
Unavailability of a separate room for taking an online class at home (HEP3)	3.08	1.39	2.67**	.47
Policy and planning-related problems (PPP)	3.02	0.71	1.44	
Lack of proper scheduling for online classes (PPP1)	3.01	1.26	0.38	.41
Difficulties in managing skilful teachers for an online class (PPP2)	2.89	1.27	-7.83**	.18
No clear policy of institution for virtual classes (PPP3)	3.26	1.27	9.89**	.48
Infrastructure and resources-related problems (IRP)	3.02	0.68	1.08	
Lack of access to the Internet at home (IRP1)	2.82	1.37	-6.35**	.36
High cost of Internet for an online class (IRP2)	3.39	1.31	-7.65**	.29
Lack of access to digital devices for taking an online class at home (IRP3)	2.80	1.28	14.12**	.46
High cost for digital devices (IRP4)	3.22	1.30	7.99**	.43
Lack of access to learning resources during online learning (IRP5)	2.86	1.28	-5.29**	.31
Mathematics achievement	57.25	17.14	20.34*	

**p<0.05, **p<0.01, ITC- Item total correlation*

Relationship between CLLM through VMI-Related Items

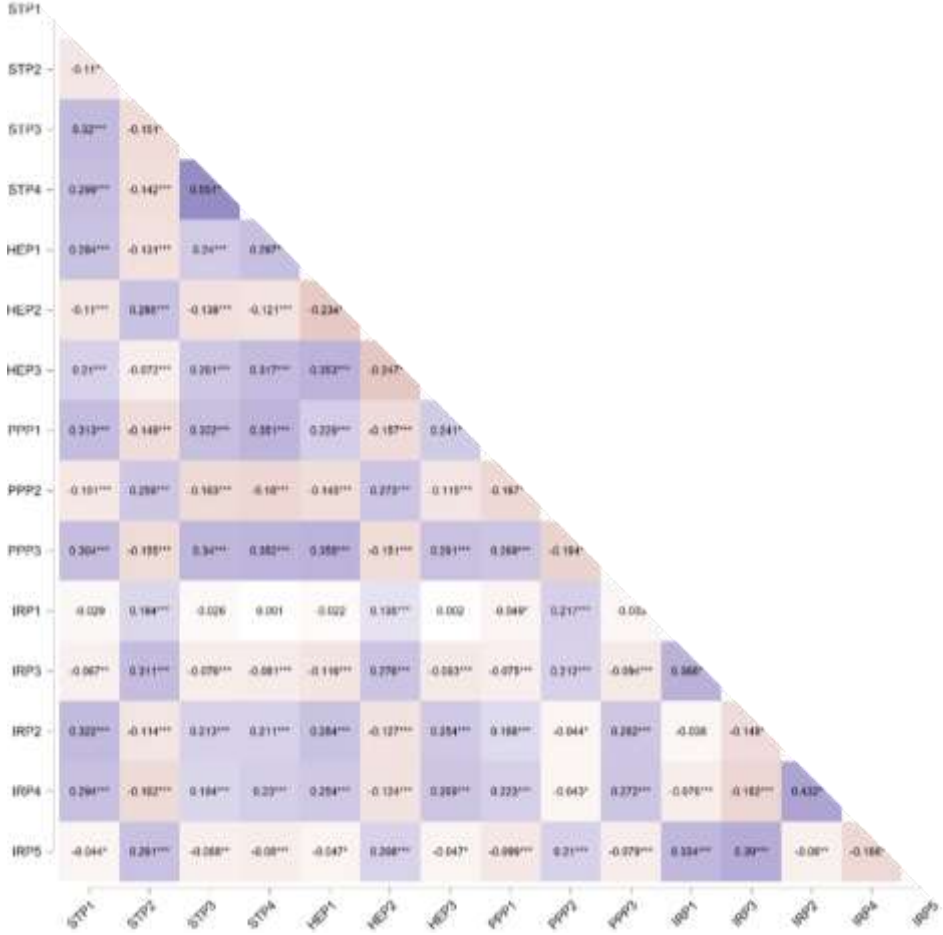

Figure 2
Correlation between the CLLM through VMI (**p<0.05, **p<0.01)*

Figure 2 presents the relationship among all items of CLLM through VMI. The red color represents negative, and the black color represents the positive correlation, and the brightness of the color depends on the correlation values. The Spearman's Rho correlation was employed to calculate the relationship between the variables because of having ordinal data (Verma & Abdel-Salam, 2019; Walliman, 2011). The moderate and significant positive correlation was found between STP3 and STP4 ($r=0.55$, $p<0.01$), IRP2 and IRP4 ($r=0.43$, $p<0.01$), and IRP3 and IRP5 ($r=0.39$, $p<0.01$) (Burns & Dobson, 1980, p. 247). A low and slightly significant relationship was found in the remaining cases except for IRP1 with STP1, STP3, STP4, HEP1, HEP3, and PPP3 and IRP2 with IRP1.

Effect of Parents' Background and CLLM through VMI on Mathematics Performance

Results of hierarchical linear regression from Model 1 to Model 4 are presented in Table 2. The models explain 4% to 7% variance with significant ANOVA in each case with 0.03 to 0.06 adjusted R^2 values indicating that the models are the poorest fit (Cohen et al., 2007). Table 2 further shows that Model 1 has four significant predictors of achievement as complications of digital resources-related training, assignment preparation, and assignment submission. Model 2 was developed by controlling skills and training-related complications, and the results show that all items related to the home environment are significant predictors of achievement; however, all predictors have negative effects. Moreover, Model 3 was developed by extra loading policy and planning related items in the previous model; however, only one additional predictor, a clear policy of school for virtual classes found to be significant. In Final Model 4, access to the Internet, digital devices, learning resources and the cost of digital devices were found to be additional significant predictors.

Table 2
Effect of CLLM through VMI on Mathematics performance (n=2311)

Items	Model 1		Model 2		Model 3		Model 4		Coef
	Beta	VIF	Beta	VIF	Beta	VIF	Beta	VIF	
STP1	-0.05*	1.33	-0.06*	1.26	-0.07*	1.19	-0.10*	1.15	-0.06
STP2	0.00	1.26	0.00	1.16	0.00	1.11	-0.01	1.03	-0.01
STP3	-0.08*	1.55	-0.08*	1.54	-0.09*	1.51	-0.10*	1.50	-0.06
STP4	0.00	1.64	-0.01	1.63	-0.01	1.56	-0.05*	1.47	0.00
HEP1	-0.07*	1.34	-0.09*	1.32	-0.10*	1.27			-0.06
HEP2	-0.07*	1.27	-0.07*	1.23	-0.08*	1.18			-0.05
HEP3	-0.08*	1.32	-0.09*	1.29	-0.10*	1.27			-0.03
PPP1	0.02	1.27	0.02	1.26					0.00
PPP2	0.00	1.22	-0.02	1.17					-0.02
PPP3	-0.06*	1.37	-0.07*	1.35					-0.07
IRP1	-0.07*	1.25							-0.08
IRP3	0.05*	1.40							0.02
IRP2	-0.03	1.36							-0.03
IRP4	-0.05*	1.39							-0.08
IRP5	-0.05*	1.32							-0.01

**p<0.05; Coef-Coefficients (β) obtained from machine learning*

Results of Machine Learning

Regularized linear regression model under machine learning was performed in the research. The total sample was performed in three fragments as train (64%), validation (16%), and test (20%). The evaluation matrices shows that the model have 0.90 mean square error (MSE), Mean Absolute Error (MAE)/Mean Absolute Deviation (MAD) found to be 0.78 with R square 0.09. The beta coefficient is near to similar with Model 4 of hierarchical linear regression which is presented in the last column of Table 2 and Figure 3(a). Figure 3(b) shows a scatter plot showing a negative correlation between prescribed test values as complications of learners in learning mathematics online and

observed test values as mathematics achievement. This means that as the complications of learners in learning mathematics online increase, the mathematics achievement score tend to decrease. Figure 3(c) shows the relationship between the regularization parameter λ and the MSE of a regularized linear regression model on the validation set. The MSE is a measure of how well the model predicts unseen data and lower MSE indicates a better model (Kim & Won, 2018; Gupta et al., 2009; Willmott & Matsuura, 2005) however that value found to be 0.90 hence model is poor fit in this research. The graph also shows that the MSE on the validation set is relatively flat for a range of values of λ which indicates that it is not necessary to tune the regularization parameter very precisely in order to get a good model.

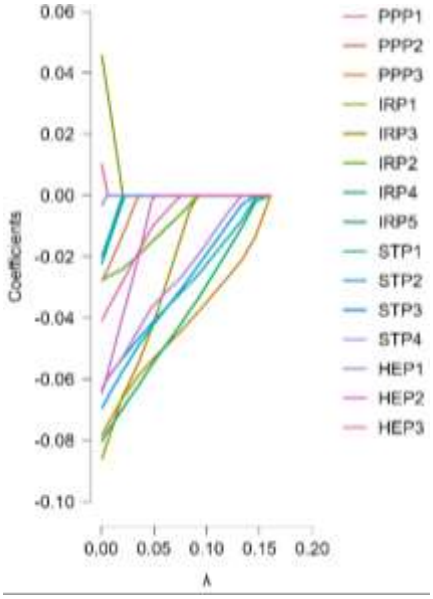

Figure 3(a)
Variable Trace Plot

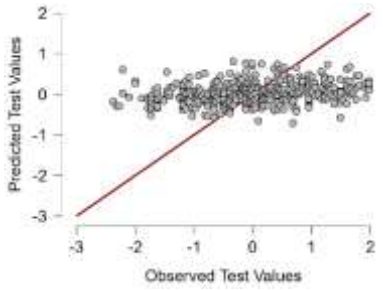

Figure 3 (b)
Predictive Performance Plot

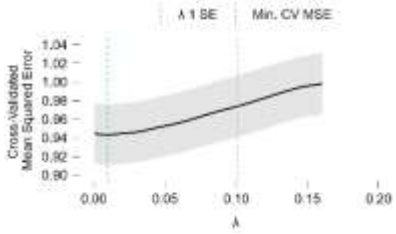

Figure 3(c)
Lambda Evaluation Plot

DISCUSSION

The study focused on the effect of CLLM through VMI on learning achievement. Access and cost of digital resources related problems under infrastructure problems were found to be higher than others, which may be the cause of greater economic diversities (Jæger & Blaabæk, 2020; Jelińska & Paradowski, 2021; Lembani et al., 2020), whereas access and cost of the Internet at home are measured as minor problems (Adhikari et al., 2023; Joshi, Adhikari, Khanal, et al., 2023; Joshi, Chapai, & Khanal, 2023), which is against the findings of Hillier (2018), Thapa and Sein (2018), and Zhou et al. (2011) in developing and developed country contexts. In this study, this contradictory result was due to the sampling error that this research data was collected from institutions with access to the Internet and the provision of online classes.

Training in using digital resources and assignment submission were found to be major challenges under the skill and training-related complication, which may cause the online classes to be new in the Nepali context, where Al-Salman & Haider (2021) also suggested that technical care and content-related digital tools are needed for effective virtual learning (Pandit & Agrawal, 2021). The policy of institutions for the virtual class was found to be another common problem because educational institutions followed face-to-face mode. The lack of digital literacy among parents and the absence of a separate room at home were home environment-related problems, indicating that parents' knowledge of using digital tools and technology is connected with their children's learning in an online environment, as in the study of Khlaif et al. (2021) and Joshi, Chapai, and Khanal (2023) which may not have the idea to link digital resources with the learning activities of their children. Communication problems were found to be minor as compared to others, which may be because Facebook, Viber, WhatsApp, and other tools are common to the general public. Butnaru et al. (2021) suggested that access to the Internet and digital resources is important for effective online learning. Mishra et al. (2020) showed that the role of the government should be impressive in managing digital resources. These problems exist not only in developing countries like Nepal but even in high-income countries like Romania (Beyene et al., 2020; Coman et al., 2020); therefore, concerned stakeholders should address the issues. Among the four dimensions, skills and training-related problems were found to be higher; hence, training on the use of digital resources focusing on online learning should be designed and implemented.

Complications in digital resources-related training and assignment preparation negatively affect mathematics performance under skills and training-related complications; hence, further awareness and training on the application of digital resources, assignment preparation, and submission are needed for the student's performance enhancement. This finding is in accordance with the conclusion of Suh (2010), who found that highly efficient use of technology as a tool can assist in learning achievements. Parents' digital literacy and motivation and separate room-related complications negatively affect learning performance; hence, parents should focus more on enhancing their digital literacy. Furthermore, the government, institutions, and teachers should have additional programs for motivating parents toward the virtual mode of instruction. For teachers, students, and parents to use digital tools ethically and for improved learning and teaching, the relevant stakeholders must create and implement unique programs (Khanal et al., 2021). The institution's policy for virtual instruction has a negative effect on learning performance; hence, concerned institutions must have clear policies, strategies, and guidelines for implementing a virtual mode of instruction.

Teachers are viewed as social change agents (Badley, 1986; Bourn, 2015) and main stakeholders in implementing virtual modes of instruction, so for mathematics teachers to employ digital technologies, they must be digitally literate, as well as have ethical, cultural, leadership, and policy awareness (Nguyen & Habók, 2023; Wohlfart & Wagner, 2023; Erdem et al., 2023; Khanal et al., 2021). Furthermore, access to the Internet and learning resources and the cost of digital resources also negatively affect learning performance (Li et al., 2023); hence, the government, institutions, and other

education-related supporters should have additional plans like free Internet for students, incentives for managing digital devices and digital resources for the students. Compared to all indicators, home environment-related factors contribute more to determining learning performance; hence, additional support is needed to promote these activities. Egunsola (2014) also found that home environment factors (Elliott et al., 2023) such as parental educational qualification, occupation, economic status, and home location are correlated with students' academic performance.

CONCLUSION

The level of complication experienced by learners in learning mathematics was found to be significantly high that indicate they are involved in mathematics online learning activities. The finding also shows that access to and cost of digital devices, training, assignment submission, digital literacy, and a separate room at home were major CLLMs through VMI leading to the conclusion that complications begin from access, use and management of online classes. For effectiveness of mathematics online class, home environment-related factors like awareness and motivation of parents to manage separate study rooms are the main predictors of achievement; hence, parents' and students' digital awareness should be increased by telecasting and broadcasting digital awareness and training-related information through television and radio. Additionally, social media and newspapers can be used for their effectiveness. This study is also beneficial for policymakers for making new policies for virtual learning environments from school to university level, curriculum developers for making curriculum based on online learning, and financial supporters for allocating the budget for appropriate digital learning activities for students, teachers, and concerned stakeholders. This study is limited to online learning of mathematics in the Nepalese context, the randomness of the sample, and the survey design; therefore, further research is demanded in other subjects among developing and developed countries while maintaining randomness and following other research designs. According to the outcomes of the study, it is recommended that governmental and institutional entities formulate and execute supplementary initiatives aimed at mitigating the challenges associated with remote learning.

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