Contemporary Educational Technology, 2023, **15**(4), ep454
ISSN: 1309-517X (Online)

OPEN ACCESS

Research Article

Impact of digital skills of mathematics teachers to promote students' communication behavior in the classroom

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Citation: Joshi, D. R., Adhikari, K. P., Khanal, J., & Belbase, S. (2023). Impact of digital skills of mathematics teachers to promote students' communication behavior in the classroom. *Contemporary Educational Technology, 15*(4), ep454. https://doi.org/10.30935/cedtech/13495

ARTICLE INFO

Received: 8 Apr 2023

Accepted: 3 Jul 2023

ABSTRACT

The purpose of this study was to measure the effect of classroom practices of using communication tools, collaboration skills, digital skills, and software skills of teachers on the communication behaviors of students during mathematics instruction. A cross-sectional online survey was conducted among 466 mathematics teachers in Nepal. The primary statistical techniques applied in the data analysis were mean, standard deviation, one-sample t-test, and structural equation modeling (SEM). The results showed that the level of skill transformations of mathematics teachers in digital skills was found to be significantly low. Moreover, practices of using communication tools, collaborative skills of teachers, digital skills enhancement of teachers, and software skills enhancement of teachers were found to be significant predictors of the communication behavior of students. The results of this study suggested that teachers' technological empowerment is essential for developing digitally competent teachers who can transform the traditional mathematics classrooms into an online mode that is more constructive, collaborative, engaging, and supportive to the learners in a flexible and joyful learning environment. The study contributes to providing the knowledge of digital instructional skills of mathematics teachers to the communication behavior of the students. Moreover, the study gives an insight into using multi-group SEM in studying teachers' technological skills on students' learning of soft skills, such as communication behavior.

Keywords: collaboration, communication, communicative behavior, digital tools, mathematics teaching, transformation

INTRODUCTION

The COVID-19 pandemic created a havoc in the education system in 2020 and 2021 worldwide (World Bank, 2021). As a result of the global impact of the pandemic, more than 1.5 billion enrolled students of all ages from all over the world, or approximately 90% of the global student population, faced interruptions in their education (UNICEF, 2020). Bozkurt et al. (2020) described online classes during the COVID-19 pandemic as emergency remote education (ERE). During an ERE, the role of teachers in communicating, collaborating, digital pedagogy, and student support shifted from face-to-face mode to emergency remote learning through technological tools, such as smartphones, computers, and the Internet, which is called technological apps-mediated communication (Aslam et al., 2021; Yao & Ling, 2020). However, many teachers needed training and support to catch up with using technology and transfer the skills needed in emergency remote learning (Fraillon et al., 2019). Since then, ERE has been a norm in crisis times. Despite having several observable benefits of these technological tools, it requires an examination of how these technological tools for remote learning contribute to transforming teachers' and students' skills in communication, collaboration, digital pedagogy, and learning support. As members of the 'digital native' generation, mathematics teachers can transform their pedagogical and content knowledge and skills to remote learning to adapt to the current situations in online teaching issues (Prensky, 2001). They are expected to be relatively proficient in communication and collaboration with their students, developing their digital skills, and providing support to students to adjust in the new norm and transform the learners' behavior too (Jäger-Biela et al., 2020).

Nepal introduced information and communication technology (ICT) policy in 2000, which includes integrating computer education into the school curriculum, developing digitally competent human resources, and managing Internet connectivity in schools and classrooms (Government of Nepal, 2000). Other initiatives, such as school sector reform plan (SSRP) 2009-2015, school sector development plan (SSDP) 2016-2023, and digital Nepal framework (2019), emphasized installing ICT infrastructure and developing human resources for educational institutions (Joshi et al., 2022). These initiatives also proposed the creation of digital learning materials, the integration of ICT in the teaching and learning process, the establishment of mobile learning centers in rural areas, the facilitation of digital resources in education from school to university, and the development of an online learning platform (Ministry of Communication and Information Technology, 2019; Ministry of Education, 2009, 2016). However, the actual implementation of these policies and guidelines in the classroom context became more feasible following the outbreak of the COVID-19 pandemic.

Past studies (e.g., Izhar et al., 2021; Ozudogru, 2021; Selvaraj et al., 2021) revealed that teachers have considerable hurdles in adapting to online teaching during emergency remote learning, especially since it is a challenging task to transform their digital skills to use technology for online teaching-learning. Moreover, there is limited information on 'to what extent mathematics teachers perceived the transformation of their digitally appropriate pedagogical skills regarding communication, collaboration, digital pedagogy, and student support during the pandemic,' especially in technologically disadvantaged societies like Nepal. A few studies focused on interactions with curricular and pedagogical components (Breslow et al., 2013; Green et al., 2015; Park & Choi, 2009), use of software applications (Breslow et al., 2013; Green et al., 2015; Marks et al., 2005; Park & Choi, 2009), and prior experience, all of which play a role in how comfortable students and teachers are with communication and collaboration (Hendrix et al., 2017) when using emergency remote learning. These studies were conducted in different contexts outside of Nepal and before the pandemic situation. Moreover, the studies done in the Nepali context revealed that remote learning is challenging due to the lack of digital infrastructure and internet connectivity (Gnawali et al., 2022; Shakya et al., 2018; Sharma & Bhatta, 2018).

Currently, mathematics teachers are increasingly utilizing digital tools to facilitate remote collaboration among student groups and enhance their collaborative, communicative, and pedagogical skills (Andersen & Rustad, 2022; Hillmayr et al., 2020). However, the implementation of digital tools and pedagogy in the Nepali education system has not progressed as smoothly or rapidly as expected, despite the increased demand following the COVID-19 pandemic (Joshi et al., 2023). Some concerns have also been raised about teachers' and students' competencies in collaboration, communication, learning support, and pedagogical nature (Al Mahdawi et al., 2021; Joshi & Adhikari et al., 2022). Research on teachers' and students' transformation of digital skills for communication, collaboration, and student support in technologically disadvantaged societies in remote areas is limited. In this context, it is necessary to examine teachers' and students' familiarity and skills transformations with the usage of technology in emergency remote learning during COVID-19 (Chugh & Ruhi, 2018; D'Aquila et al., 2019; Holmes & Rasmussen, 2018; Voivonta & Avraamidou, 2018). Therefore, in light of the needs of digitally transformed teachers in the present context, this study aimed to unveil the grave situation of mathematics teachers about using digital and technological tools to facilitate remote learning in a developing country like Nepal.

Objective and Research Questions

The objective of this study was to assess how do mathematics teachers perceive and self-report their practices of transforming communication, collaboration, digital technology, and student support skills to promote their communication behavior. Therefore, we proposed the following research questions to achieve this objective:

1. What are mathematics teachers' perceptions towards the skill transformations in digital and software enhancement skills, collaboration skills, use of communication tools, and students' communication behaviors during online teaching of mathematics?
2. How do teachers' skills of collaboration and use of communication tools moderate with their digital and software-using skills to impact students' communication behaviors?

LITERATURE REVIEW

In light of the swift implementation of COVID-19 lockdown measures, the ramifications were experienced across various domains of life that escalated to an unparalleled magnitude (Iqbal et al., 2020). Undoubtedly, the education sector has not been exempted from the profound challenges posed by this global crisis. The stringent implementation of lockdown measures, adherence to social distancing protocols, and the implementation of COVID-safe hygiene practices had presented formidable challenges for numerous higher education establishments globally, rendering traditional face-to-face course delivery methods virtually unattainable. In response to these unprecedented circumstances, a compelled shift towards remote learning emerged as the sole feasible alternative, effectively averting the imminent shutdown of countless educational institutions (Turnbull et al., 2021). Emergency remote learning encompassed various approaches, including e-learning, blended learning, and mobile learning, which had all been employed to facilitate education during the time of crisis (Ajayi et al., 2019). While these methods differed in execution in a great deal, they shared a commonality in being delivered remotely (Means et al., 2010), with the primary goal of enabling students to engage in virtual learning and group discussions (Omar et al., 2021). In the virtual classroom setting, instructors relied heavily on communication tools such as email, chat platforms, and other virtual media to interact with their students (Alawamleh et al., 2020; Al Tawil, 2019), fostering a sense of community within the online learning environment (Upadhayaya et al., 2021). Through these means of communication, instructors tried to impart knowledge and information, supporting students in comprehending the subject matter and establishing meaningful learning relationships within the class (Khalil et al., 2020). Thus, emergency remote learning involved various approaches such as e-learning, blended learning, and mobile learning, to name a few. These methods aimed to facilitate virtual group discussions and fostered a sense of community among students (Omar et al., 2021). Instructors utilized communication tools to provide knowledge and support, ensuring students could comprehend the subject matter and build learning relationships in the online environment (Joshi et al., 2022).

During the COVID-19 pandemic, numerous studies explored the challenges and opportunities associated with the abrupt shift to remote learning. For instance, Wang's (2023) research focused on university students from prestigious institutions worldwide, revealing mismatches in expectations, roles, activities, and realities that had detrimental effects on students' learning and adjustment in remote learning environments. Raja et al. (2023) found that the unplanned transition to remote learning led to a loss of social identity and a diminished sense of belonging among students. Meanwhile, Bork-Hüffer et al. (2023) indicated that although remote learning had improved since the initial lockdown, students still expressed a desire for face-to-face instruction due to its social benefits. However, they also emphasized the importance of maintaining the options for remote learning even after the pandemic. In contrast, Biberman-Shalev et al. (2023) highlighted the success of synchronous frontal lectures via Zoom, while also noting the effectiveness of integrating MOOCs, YouTube, and Podcasts. These studies shed light on the intricacies of the transition to remote learning during the pandemic and offered valuable insights into potential strategies for enhancing teaching and learning in the post-pandemic era. However, it is worth noting that these studies largely overlooked the impact of teachers' digital skills in specific subjects like mathematics, science, and language teaching, which could play a crucial role in promoting students' communication behavior in the virtual classrooms.

There is a growing body of literature on teachers' and students' perceptions of remote learning. For example, Aslam et al. (2021) revealed the perceptions of students and teachers in remote learning in Turkish English teaching classrooms and revealed that their perceptions of remote language learning effectiveness and the challenges faced during online classes. While many participants preferred traditional on-campus lessons, a notable number of teachers expressed positive attitudes toward online education. However, their positive attitudes did not necessarily mean that they preferred online classes over in-person ones. Similarly, Yao and Ling (2020) highlighted how technological tools could impact social and behavioral processes. The combination of networked computing, big data processing, and mobile communication led to technological advancements in media and communication, prompting scholars to reconsider human communication in various aspects and forms. These studies highlighted the significance of digital tools in shaping and altering human communication behaviors, including teachers and students. They emphasized the transformative role of technology in influencing how teachers and students interact and communicate with each other efficiently and effectively.

Alawamleh et al. (2020) revealed that mathematics teachers have the opportunity to acquire valuable techniques for remote learning, incorporating timely feedback for their online students. This proficiency in online teaching and learning can prove instrumental in effectively addressing emergency learning situations (Ally & Prieto-Blazquez, 2014; Bansal & Dhananjay, 2014). Nevertheless, there remains a lack of comprehensive research examining the extent to which it enhances the teacher's aptitude in utilizing communication tools to facilitate interaction between educators and students (Ally & Prieto-Blazquez, 2014; Bansal & Dhananjay, 2014). The unprecedented shift to online learning necessitated by the COVID-19 pandemic has likely brought about a transformation in the communication skills of both teachers and students, fostering the exploration of novel modes of communication and collaboration (Zarzycka et al., 2021). The research mentioned highlights the importance of mathematics teachers adapting to remote learning and acquiring new skills to effectively engage students in online sessions. While the benefits of online teaching and timely feedback are acknowledged, there is a need for further investigation into the specific impact on teachers' communication abilities. Additionally, the COVID-19 pandemic has likely prompted a shift in communication dynamics between teachers and students, leading to the exploration of alternative methods for effective interaction and collaboration.

The findings presented by Zarzycka et al. (2021) provided valuable insights into the positive impact of social media platforms on online classes, leading to improved collaboration between students and students and teachers. These points further highlighted the importance of collaborative learning, which could foster interaction and shared construction of knowledge among individuals (Dillenbourg, 1999a). The integration of collaborative learning in virtual classes not only supported the co-construction and exploration of mathematical concepts and meanings but also facilitated the development of higher-order thinking skills (Palloff & Pratt, 2005). The use of various digital tools such as OneDrive, OneNote Classroom, Docs, Slides, Files, Jam Boards, and Forms further enhanced the collaborative experience between teachers and students in remote learning (Green et al., 2020). These reflections emphasized the potential of online classes to promote collaborative learning and its positive implications for the educational processes.

In the remote learning situation, teachers should have some necessary skills-- such as digital skills, communication, and collaboration skills. Digital skills are essential in a virtual learning environment (UNESCO, 2008, 2016) because without skills in using digital tools, software, and resources teachers cannot run their classes effectively (Joshi, et al., 2021; Sales et al. 2020). Similarly, establishing good communication channels, developing communication behaviors with peers and students and having skills to motivate students to communicate with their teachers and peers are equally important in remote learning situations (Harper, 2018), and the teacher's role is crucial to facilitate interaction and discussion in remote learning (Kassandrinou et al., 2014). Therefore, the digital skills of teachers, learning support to students, effective communication, and conducting collaborative approaches are the crucial components in the remote learning environment.

In the field of mathematics education, various tools are available to enhance teaching and learning. These tools include mobile technologies with touchscreens and pen tablets, digital libraries, and the creation of new learning objects (Alabdulaziz, 2021). However, to fully harness the pedagogical benefits of these tools, teachers and students have to possess digital skills (Drijvers, 2015). Despite their widespread uses, the impact of these tools on learning outcomes remains inconclusive (Joshi et al., 2022). Notably, past research indicated that while low-performing students tended to spend more time using digital technologies, it was often for non-school-related purposes (Hietajärvi et al., 2019). Both average and low-performing students resorted to digital technologies as a means to escape tedious classes (Bergdahl et al., 2019; Hietajärvi et al., 2019). Interestingly, highly educated individuals leveraged digital technologies to extend their knowledge and skills, thereby benefiting their future prospects (van Dijk, 2005). In today's digital age, children are surrounded by computers, the Internet, and various social media platforms such as Instagram, Facebook, Twitter, and many more tools and applications (Jukes et al., 2010). They actively seek knowledge and engage with others online, often maintaining websites with blogs and online profiles (Curtis, 2009). In light of this digital environment, mathematics teachers should continually update their skills to effectively utilize these tools in teaching and monitoring their impact on students' mathematical learning. Thus, while digital tools offer great potential in mathematics education, it is crucial to consider factors such as digital skills, usage patterns, and the changing digital landscape. Teachers may play a vital role in adapting to these advancements, ensuring that these tools are effectively employed to promote meaningful learning experiences for students, and to enhance their communication behavior in the classrooms or outside.

METHODOLOGY

The authors of this study are faculty members at different higher education institutions who have been teaching mathematics education courses at undergraduate and graduate levels in Nepal and abroad. They are familiar with the different usage of digital tools in engaging and supporting preservice mathematics teachers in meaningful discussions on the issues of teaching and learning mathematics. They all went through experiences of transitioning from face-to-face to online teaching during the COVID-19 pandemic. While they grappled with the uncertainties of using a variety of digital and online tools for the continuation of teaching and learning, they were also involved in training mathematics teachers in using such tools in mathematics teaching and engaging students for effective communication and collaboration in the classroom. In this context, they were interested in examining the impact of digital skills of mathematics teachers to promote students' communication behavior in the classroom during the COVID-19 pandemic and thereafter. In this context, this study adopted a cross-sectional survey design with an online questionnaire administered to participants during the COVID-19 pandemic.

Sample and Sampling Technique

The population for this study included 1,572 mathematics teachers who participated in different workshops and training (Khanal et al., 2022). Because of technology-related information in the instrument, the researcher recruited those teachers who participated in the different technology-related trainings during the COVID-19 pandemic. On the other hand, it was difficult to collect data in face-to-face mode during the COVID-19 pandemic, and other irrelevant persons may participate in the survey while using other social media, hence researcher used a list of mathematics teachers in the research. The questionnaire link to Google Forms was shared with all of them through an email list. Hence, the list-based sampling technique (Fricker, 2017; Schonlau et al., 2002) was adopted in the research. For the informed consent of participant (confidentiality and anonymity), clear instruction was given in the Google Form as voluntary participation, their right not to participate, may stop participation at any moment, confidentiality, password protected electronic database, anonymity of participants, and use of data for research purpose only. However, only 466 mathematics teachers returned the survey on time during the period August to October 2021. Hence, it was considered that the sample for this study was 466 mathematics teachers who responded to the online questionnaire.

Research Instrument

A research team constructed an online questionnaire with 20 items on a five-point Likert scale from strongly agree to strongly disagree. The items of the questionnaire were based on the contemporary issues of online teaching and learning of mathematics using digital tools. The five dimensions as the variables of interest in this study were as follows:

Table 1. Validity & reliability of the instrument

Construct	α	CR	AVE	Discriminant validity				
				PUCT	CBS	CST	DSET	SUSET
The practice of using communication tools (PUCT)	0.87	0.88	0.71	0.84				
Communicative behavior of students (CBS)	0.90	0.90	0.65	0.61	0.81			
Collaboration skills of teachers (CST)	0.86	0.86	0.61	0.61	0.51	0.78		
Digital skills enhancement of teachers (DSET)	0.92	0.92	0.75	0.71	0.78	0.52	0.86	
Software using skills enhancement of teacher (SUSET)	0.93	0.93	0.77	0.60	0.43	0.77	0.63	0.88

Teacher's practice of using communication tools

Teacher's practice of using communication tools (TPUCT) dimension measured teachers' virtual classroom practices in using digital communication tools to communicate with students and teachers in teaching and learning mathematics. This variable uncovered how far teachers communicated with students and co-workers to facilitate learning activities (Belbase et al., 2021; Sukthankar et al., 2009).

Communication behavior of students

Under communication behavior of students (CBS), the items included questions related to the students who were shy in face-to-face classrooms could easily communicate with the teachers, communicate more frequently with teachers, personal communication with other students became more accessible, safe to communicate, and easy to share any problems with teachers during online instruction (Joshi et al., 2021; Zarzycka et al., 2021).

Collaboration skills of teachers

This dimension included items related to the easiness of collaboration, collaboration ability of teachers with their peers and students, the use of OneDrive and OneNote to collaborate with students, and the use of google drive (classroom, docs, slide, file, Jam board, and form) to collaborate with students (Dillenbourg, 1999b; Green et al., 2020).

Digital skills enhancement of teachers

Digital skills enhancement represented the necessary skill of teachers for using digital resources for their instructional activities. How mathematics teachers learned or enhanced their technological skills was the primary concern of this domain. Hence, this dimension included items related to the enhancement of digital pedagogical skills from online training, participation in the online courses, collaboration, and self-practice with these digital tools.

Software using skills enhancement of teacher

How mathematics teachers enhanced their mathematical software using skills was the main concern of this domain. Hence, items related to this dimension were-- learning to use mathematical software from training, watching the online tutorials, using user's guides, and participating in online course-related information.

Validity and Reliability of the Instrument

The internal consistency of the research instrument was ensured by Cronbach's alpha method, and it was found to be 0.95, which exceeds the threshold value of 0.70 (Cohen et al., 2018), and hence the instrument was considered a reliable one. The dimension-wise reliability was also calculated by the same method and found to be in between 0.86 to 0.93 for all the five sub-scales (**Table 1**). Moreover, the reliability of the research instrument was also ensured by the construct reliability (CR) technique and found to be greater than 0.70, which exceeded the threshold criteria (Civelek, 2018). For the construct and content validity of the tool, the questionnaire was shared among four educators of higher education institutions who were also research experts. The four educators provided some minor comments on the language and structure of items with almost 80% of inter-rater reliability as they agreed upon all 16 items and pointed out four items to make some corrections out of 20 items. Furthermore, the validity of the instrument was ensured by face, convergent, and discriminant validity techniques. Confirmatory factor analysis (CFA) was employed to ensure the dimensions of the instrument. Based on CFA, all items were categorized into five dimensions: practice of using communication tools (PUCT), CBS, collaboration skills of teachers (CST), digital skills enhancement of teachers (DSET), and software using skills enhancement of teacher (SUSET). The construct validity was ensured by the average variance extracted (AVE), which was found to be greater than 0.50 in each construct, indicating that the tool was valid (Civelek, 2018). Additionally, the correlation score between pairs of constructs was found to be less than the square root of AVE (**Table 1**), which justified that the discriminant validity with an appropriate fit in the instrument (Nusair & Hua, 2010).

Data Collection Procedure

The data were collected online using an online questionnaire in Google Forms. The questionnaire was administered to 1,572 secondary mathematics teachers who participated in one month of virtual GeoGebra and technology training organized by Society of Technology Friendly Teachers (STFT) and Council of Mathematics Education of Nepal. The participants were informed about the purpose of the study, their right to withdraw from the study, the safety of their identity with the anonymity of the data, and their contribution to the knowledge construction through participation in the study. The initial number of participants circulating the questionnaire was about 3% of the total tentative number of mathematics teachers in Nepal. We used an online sample size calculator (https://www.calculator.net/sample-size-calculator.html) to reach a proper sample size from 54,253 mathematics teachers in Nepal, out of which 1,572 were sent the questionnaire. For a 95% confidence interval for a population size of 54,253, the sample calculator yielded a feasible sample size of 382. However, 466 respondents participated in the research during the data collection period (August to December 2021); therefore, our goal was to exceed this number and hence reached a reasonable sample size.

Sample Characteristics

Gender and institution types were used in sample characteristics in the research. Whereas gender had two categories as female and male, and types of institutions had two categories: public and private institutions. Among the 466 mathematics teachers who participated in the research, 45 (9.66%) were females, and 421 (90.34%) were males. Based on types of institutions, 117 (25.11%) were from private institutions, and 349 (74.89%) were from a public institution.

Data Analysis Technique

The data were analyzed by descriptive statistics and structural equation modeling (SEM) techniques. The mean (M) and standard deviation (SD) were computed to show the item-wise and dimension-wise status of technological skills transformation of mathematics teachers. The skills transformations were determined as high and low based on the sub-scale mean scores as above three as high and below three as low and three being the mid-point. The frequency distribution of the five dimensions in terms of high and low transformation skills was applied in the analysis. However, a one-sample t-test was also employed to test the significant mean score of items with an assumed population mean of three. SEM was used to examine the viability of the models. The results of SEM have been explained based on the R-square, beta, and lambda values. The assumptions of the model fit as outliers in the data, multicollinearity (VFI and tolerance), and homoscedasticity were assessed before the analysis.

RESULTS

The results in **Table 2** show the level of 'PCUT' skills of teachers, CBS, CST, DSET, and SUSET. The results show that these skills were found to be significantly low concerning all dimensions. However, the result was the poorest in CST compared to others. The item for using communication tools to communicate with students, teachers, and presents was found to be the poorest compared to the remaining items. Besides these results, the students who communicated more frequently with teachers online than in face-to-face situations had better results among all items. Results for each dimension have been presented separately.

Perceptions of Teachers on Digital Pedagogical Transformation

A one-sample t-test was administered to examine the significance of each dimension and its associated items in terms of skills transformation as low (below three), no transformation (close to three), and positive

Table 2. Result of descriptive statistics (n=466)

Items with categories	M	SD	t-value	FL
The practice of using communication tools (PUCT)	2.57	1.04	-9.03*	
I have been using digital communication tools to communicate with students (PUCT1)	2.43	1.22	-10.11*	0.91
I have been using digital communication tools to communicate with teachers (PUCT2)	2.48	1.14	-9.72*	0.92
I have been using digital communication tools to communicate with parents (PUCT3)	2.79	1.13	-4.12*	0.68
Communication behavior of students (CBS)	2.89	0.98	-2.51*	
Students who are shy in face-to-face classrooms can easily communicate with teacher in online (CBS1)	2.83	1.16	-3.25*	0.79
Students have been communicating more frequently with teachers online than in face-to-face situations (CBS2)	3.02	1.13	0.41	0.76
Personal (one-one) communication with a student has become more accessible in an online learning environment (CBS3)	2.87	1.19	-2.29*	0.84
Students feel safe communicating in online mode (CBS4)	2.78	1.16	-4.05*	0.84
Students can ask any type of problems (content-related or out of content related) with teachers without hesitation in online mode (CBS5)	2.92	1.13	-1.43	0.81
Collaboration skills of teachers (CST)	2.56	0.95	-10.05*	
I can easily collaborate with students in online mode (CST1)	2.62	1.10	-7.39*	0.77
I can easily collaborate with teachers in online mode (CST2)	2.48	1.14	-9.87*	0.85
I can use (OneDrive & OneNote) to collaborate with students (CST3)	2.71	1.14	-5.51*	0.66
I can use google drive (classroom, docs, slide, file, Jam board, & form) to collaborate with students (CST4)	2.41	1.17	-10.84*	0.83
Digital skills enhancement of teachers (DSET)	2.64	1.09	-7.17*	
I have enhanced my digital pedagogical skills from online training (DSET1)	2.68	1.20	-5.78*	0.85
I have developed my technological skills by participating the online courses (DSET2)	2.60	1.22	-7.00*	0.88
I have enhanced my digital skills from collaboration (DSET3)	2.68	1.18	-5.77*	0.88
I have enhanced my digital skills through self-practice (DSET4)	2.59	1.23	-7.20*	0.86
Software using skills enhancement of teacher (SUSET)	2.63	1.04	-7.62*	
I have learned to use mathematical software from training (SUSET1)	2.58	1.19	-7.66*	0.86
I have learned to use mathematical software from the tutorial (SUSET 2)	2.59	1.13	-7.76*	0.91
I have learned to use mathematical software from user's guides (SUSET 3)	2.71	1.10	-5.71*	0.87
I have learned to use mathematical software from online courses (SUSET 4)	2.65	1.16	-6.53*	0.87

Note. FL: Factor loading

Table 3. Frequency distribution of participants' responses on the five-dimension values in two categories (1-2.999 as perception of low transformation, and three or above as high transformation of skills)

Level	PUCT		CBS		CST		DSET		SUSET	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Low	314	67.4	257	55.2	297	63.7	294	63.1	285	61.2
High	152	32.6	209	44.8	169	36.3	172	36.9	181	38.8

transformation (above three) while considering three as a mid-value from the five-point Likert-scale items. The results showed that the mathematics teachers disagreed that there was a positive transformation of the PCUT (M=2.57, SD=1.04, and t-value=-9.03 with $p<0.05$). All the items within this dimension (PUCT1, PUCT2, and PUCT3) had a mean value of less than three and significant, indicating that mathematics teachers had a negative sense of the transformation in the practices of using communication tools with students, teachers, and parents through online remote teaching of mathematics during COVID-19 pandemic (**Table 2**).

The frequency distribution of mathematics teachers' self-reported low or high perceptions of transformation on PUCT showed that about 67% had a low sense of transformation on using communication tools during online remote teaching. Only 33% of mathematics teachers agreed upon communication skills transformation with remote teaching (**Table 3**). Concerning the transformation in students' communicative behavior during online remote teaching and learning, the mathematics teachers still disagreed about such transformation (CBS: M=2.89, SD=0.98, t-value=-2.51, and $p<0.05$). The item-wise results showed that two items (CBS2 and CBS5) were not statistically significant from the neutral view ($p>0.05$), and the rest of other three items were significant but negative (mean values lower than three), indicating that mathematics teachers disagreed that there was any significant skills transformation in students' communicative behavior during the online learning (**Table 2**). Only 45% had a sense of high transformation in students' communicative skills during online remote mathematics teaching (**Table 3**).

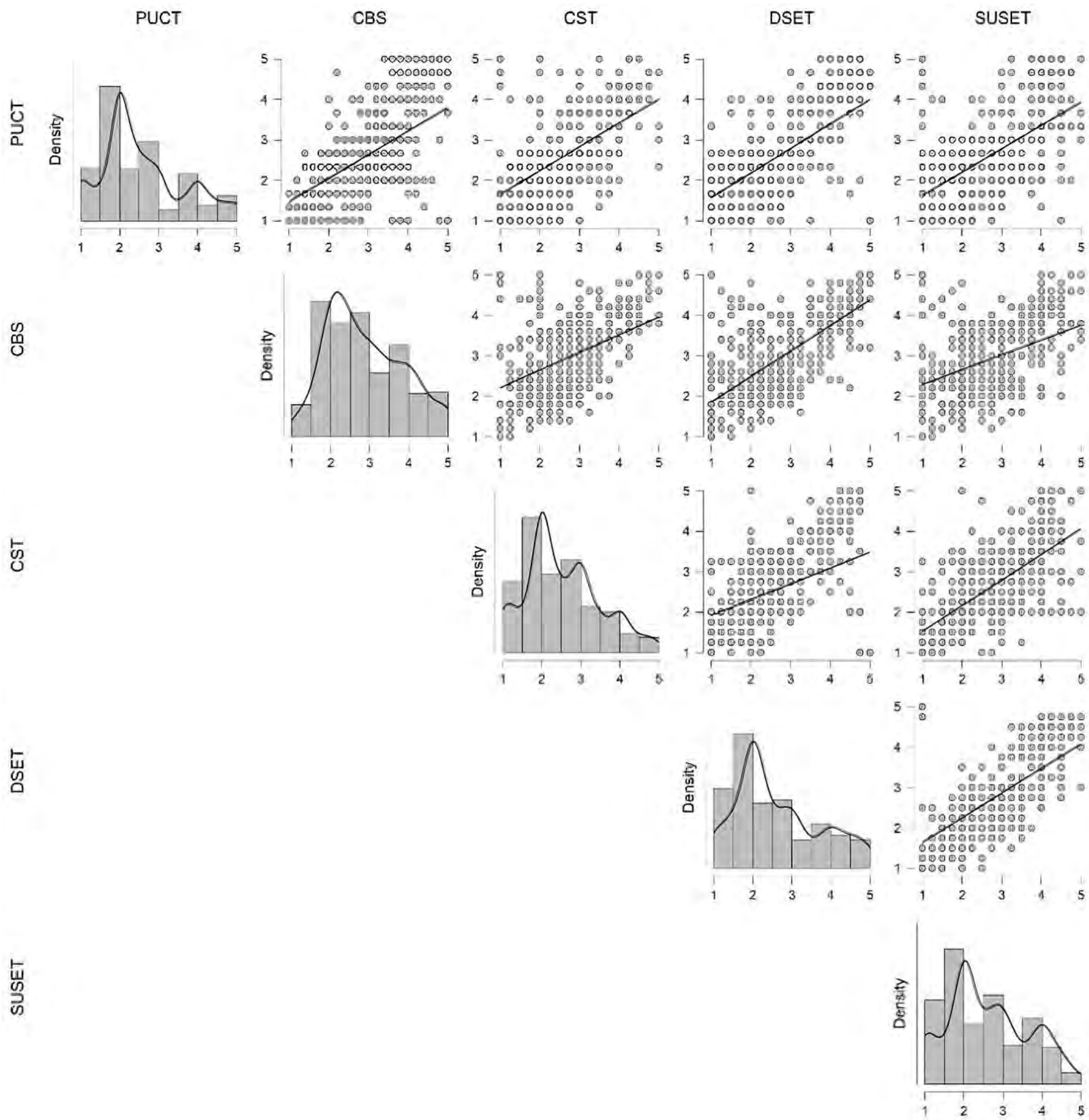

Figure 1. Visual representation of the correlation between the dimensions (Source: Authors)

On the transformation of mathematics teachers' collaboration skills (CST), the one-sample t-test results showed that they were not optimistic about their skills transformation during the online remote teaching (CST: M=2.56, SD=0.95, t-value=-10.05, and $p<0.05$). The item-wise analysis within this dimension showed that they did not agree with any of the four statements (CST1, CST2, CST3, and CST4), and the results were statistically significant ($p<0.05$). Only 36% of the mathematics teachers had a sense of high collaborative skills transformation due to online remote teaching during the COVID-19 pandemic (**Table 3**). The results were significantly negative for the other two dimensions (DSET and SUSET) and their associated items at 0.05 level of significance, indicating a poor skills transformation on digital skills and SUSET (**Table 2**). About 37% and 39% of mathematics teachers had a high sense of skills transformation on DSET and SUSET, respectively (**Table 3**).

The relationship between the five dimensions is presented in **Figure 1**. The relationship was found to be positive and significant (at 0.05 level) between all pairs of variables. The correlation coefficient was found to be 0.43 between learner communicative behavior and SUSET, and it was 0.78 between learner communicative behavior and DSET, and both correlations were statistically significant at a 0.05 level. The detail of the correlation value is presented in **Figure 1**.

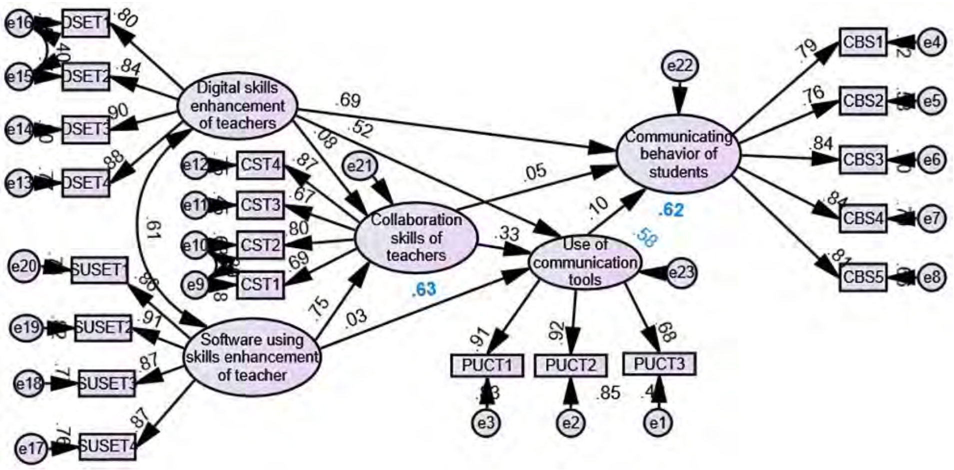

Figure 2. SEM results with respect to the total sample (Source: Authors)

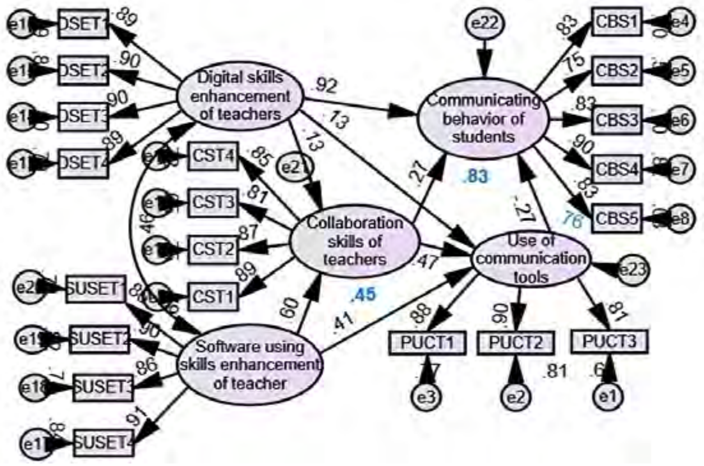

Figure 3. SEM results based on female respondent (Source: Authors)

Structural Equation Modeling: Model Fit Indices with Threshold Criteria

The sample size was 466, and the observed variables were 20; hence the sample size was sufficient for SEM analysis (MacCallum et al., 1996). The significant value of the chi-square was considered in the models (Bentler & Bonett, 1980) because of the appropriate fit of remaining indicators as root mean square error of approximation (RMSEA), which was 0.04 (<0.08), goodness-of-fit statistic (GFI) was 0.86, adjusted goodness-of-fit statistic (AGFI) was 0.81 (near to threshold value 0.90), and standardized root mean square residual (SRMR) was 0.06 (<0.08). Further, the normed-fit index (NFI) was 0.90 (>0.09), comparative fit index (CFI) was 0.93 (>0.90), Tucker-Lewis index (TLI) was 0.92 (>0.90), and incremental fit index (IFI) was 0.94, all indices indicated a good fit (Bentler & Bonett, 1980; Byrne, 1989; Hooper et al., 2008; Hu & Bentler, 1999; Kline, 2016; MacCallum et al., 1996; Sarker & Chakraborty, 2021) in the model. The modification indices were applied for improvement of the model because of getting CMIN/DF=2.54, GFI=0.87, AGFI=0.83, NFI=0.92, IFI=0.95, TLI=0.94, CFI=0.9t, RMSEA=0.03, and SRMR=0.08 in the model, where the GFI, AGFI, and RMSEA were not meet the threshold criteria. The detailed results of SEM have been presented in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6.

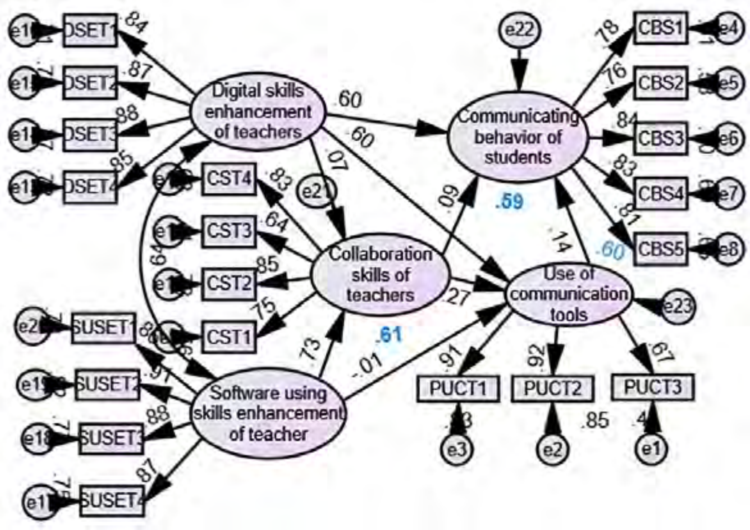

Figure 4. SEM results based on male respondent (Source: Authors)

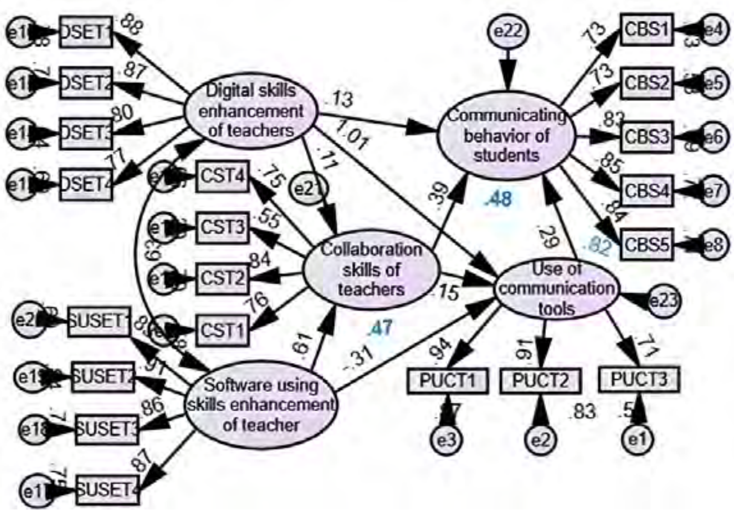

Figure 5. SEM results based on the respondents from a private institution (Source: Authors)

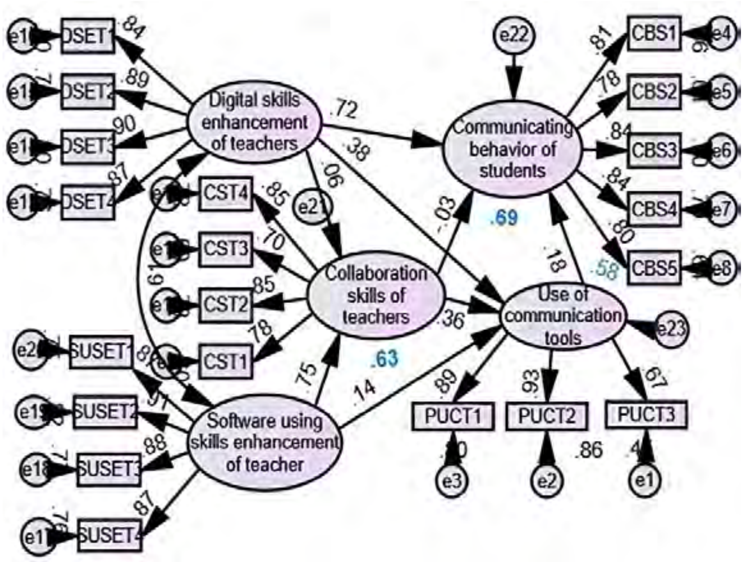

Figure 6. SEM results based on the respondents from public institution (Source: Authors)

Results of Structural Equation Modeling

In this section, the results of SEM were calculated based on the total respondent and with separate categories of sample characteristics as female and male participants and participants from private and public institutions. The model explained 63%, 62%, and 58% variances in CST, PUCT, and CBS, respectively, while taking all participants. Moreover, the model explained 45%, 83%, and 76% variance concerning females, 61%, 59%, and 60% concerning males, and 47%, 48%, and 82% variance among participants from private institutions, and 63%, 69%, and 58% variance concerning the participants from the public institutions.

Results of association of SUSET and DSET (H1)

The model showed that the relationship found to be similar concerning the participants in total, males, from private and public institutions (correlation value from r=0.61 to 0.64) between DSET and SUSET; however, that relationship was found to be low (r=0.46) concerning females.

Effect of DSET on CST, PUCT, and CBS (H2-H4)

Figure 2, **Figure 3**, **Figure 4**, **Figure 5**, and **Figure 6** show that the DSET has a significant effect concerning all participants in PUCT and CBS, whereas similar results were reported concerning male, private, and public institution teachers; however, the effect is significant in the case of CBS for females. Moreover, the DEST has the highest effect on PUCT (beta=1.01) for the participants from a private institution. However, DEST does not affect CST in all cases.

Effect of SUSET on CST and PUCT (H5-H6)

In **Figure 2**, **Figure 3**, **Figure 4**, **Figure 5**, and **Figure 6**, it can be shown that the CUSET have a significant positive effect on CST in each case. The effect is significant in PUCT concerning female participants and participants from public institutions; however, the effect is negative concerning the participant from private institutions. In the remaining cases, the results were found to be insignificant.

Effect of CST on PUCT and CBS (H7-H8)

Figure 2, **Figure 3**, **Figure 4**, **Figure 5**, and **Figure 6** show that the effect of CST was found to be positively significant on PUCT in each case except in the case of the teachers from a private institution. Furthermore, the CST has a significant positive effect in the case of female teachers and those teachers from a private institution.

Effect of PUCT on CBS (H9)

The PUCT has a significant effect on CBS concerning male participants and participants from public institutions. In contrast, the result was found to be insignificant in the remaining cases. The PUCT has a negative effect on CBS with female participants; however, the result showing to be insignificant.

Table 4 shows the details contribution of each item on each dimension based on the results of total participants and sample characteristics. The factor scores weights (FCW) of SUET1 were found to be highest on SUSET concerning females (0.19), indicating that when SUSET1 increased by one unit, the SUSET increased by 0.19 unit and least concerning the respondents from the private institutions (0.15). In contrast, the result is similar in the remaining cases. The results were found to be similar in the case of SUSET4. SUSET2 is central in determining SUSET for a private institution and female participants. Besides SUSET-related items, the role of CST4 is the highest compared to the remaining items in SUSET; however, the role of PUCT1 and PUCT2 have negative for the participants from private institutions. DSET3 has a central role in determining DEST concerning all cases except female participants because DSET1 has the leading role for females. Besides, the items of DEST, CBS, and PUCT-related variables have more contribution in DSET concerning total, female, male, and participants from public institutions; however, PUCT and SUSET-related variables have a leading role for the participants from private institutions. CST4 has a prominent role in determining CST for all cases.

In contrast, SUSET and PUCT-related items, as compared to others, are the main predictors to determine CST, excluding CST-related variables. PUCT1 and PUCT2 are the main predictors of the PUCT concerning all types of participants. CST4 and SUSET-related variables are the main predictors to determine PUCT concerning all types of participants except the participants from private institutions among all the variables

Table 4. Factor score weights of items in PUCT, CBS, CST, DSET, & SUSET concerning sample characteristics

		SUSET 1	SUSET 2	SUSET 3	SUSET 4	DSET 1	DSET 2	DSET 3	DSET 4	CST 4	CST 3	CST 2	CST 1	CBS 5	CBS 4	CBS 3	CBS 2	CBS 1	PUCT 1	PUCT 2	PUCT 3
SUSET	T	.17	.28	.21	.19	.00	.01	.01	.01	.04	.02	.02	.01	.00	.00	.00	.00	.00	.01	.01	.00
	F	.19	.30	.19	.29	.00	.00	.00	.00	.02	.01	.00	.00	.00	.00	.00	.00	.00	.02	.03	.02
	M	.17	.27	.20	.18	.00	.01	.02	.01	.05	.02	.03	.01	.00	.00	.00	.00	.00	.00	.00	.00
	PR	.15	.31	.20	.20	.02	.02	.02	.02	.03	.01	.02	.01	.00	.00	.00	.00	.00	-.02	-.01	.00
	PU	.17	.27	.21	.18	.00	.01	.01	.01	.05	.02	.02	.01	.00	.00	.00	.00	.00	.01	.01	.00
DSET	T	.01	.02	.01	.01	.10	.14	.31	.24	.00	.00	.00	.00	.02	.03	.03	.02	.02	.03	.03	.01
	F	.00	.00	.00	.00	.21	.20	.19	.18	.00	.00	.00	.00	.03	.05	.03	.02	.03	.01	.01	.01
	M	.01	.02	.01	.01	.09	.13	.31	.24	.00	.00	.00	.00	.02	.03	.03	.02	.02	.03	.04	.01
	PR	.02	.05	.03	.03	.14	.12	.16	.13	.00	.00	.00	.00	.01	.01	.01	.00	.01	.12	.09	.03
	PU	.01	.01	.01	.01	.09	.15	.31	.25	.00	.00	.00	.00	.03	.03	.03	.02	.03	.01	.02	.00
CST	T	.04	.06	.04	.00	.00	.00	.00	.00	.32	.12	.17	.07	.00	.00	.00	.00	.00	.03	.03	.01
	F	.01	.01	.01	.01	.00	.00	.00	.00	.39	.21	.03	.07	.00	.00	.00	.00	.00	.01	.02	.01
	M	.04	.06	.05	.04	.00	.00	.00	.00	.32	.11	.18	.07	.00	.00	.00	.00	.00	.03	.03	.01
	PR	.03	.06	.04	.04	.00	.00	.00	.00	.27	.09	.20	.09	.02	.02	.02	.01	.01	.02	.01	.00
	PU	.04	.06	.04	.04	.00	.00	.00	.00	.32	.13	.16	.07	.00	.00	.00	.00	.00	.03	.04	.01
PUCT	T	.00	.01	.00	.00	.01	.01	.02	.01	.02	.01	.01	.00	.00	.01	.00	.00	.00	.25	.30	.06
	F	.02	.03	.02	.03	.01	.01	.01	.01	.04	.02	.00	.01	.00	-.01	.00	.00	.00	.22	.31	.15
	M	.00	.00	.00	.00	.01	.01	.02	.02	.01	.01	.01	.00	.01	.01	.01	.00	.00	.26	.28	.06
	PR	-.01	-.01	-.01	-.01	.04	.03	.04	.03	.01	.00	.01	.00	.01	.01	.01	.00	.00	.30	.22	.06
	PU	.01	.01	.01	.01	.00	.00	.01	.01	.02	.01	.01	.00	.01	.01	.01	.01	.01	.21	.33	.06
CBL	T	.00	.00	.00	.00	.01	.02	.04	.03	.00	.00	.00	.00	.17	.20	.19	.13	.15	.01	.01	.00
	F	.00	.00	.00	.00	.05	.05	.05	.04	.01	.00	.00	.00	.13	.23	.14	.09	.14	.00	-.01	.00
	M	.00	.00	.00	.00	.01	.02	.04	.03	.00	.00	.00	.00	.18	.20	.20	.14	.15	.02	.02	.00
	PR	.00	.01	.00	.00	.01	.01	.01	.01	.02	.01	.01	.01	.25	.24	.21	.12	.13	.02	.01	.00
	PU	.00	.00	.00	.00	.01	.03	.05	.04	.00	.00	.00	.00	.15	.19	.18	.14	.16	.02	.02	.00

except as PUCT-related variables. The DESET-related variables have a more significant role in PUCT for the participants from private institutions.

Nonetheless, the SUSET-related variables have a negative effect. CBS4 has a central role in determining CBL concerning all types of participants except the participants from private institutions because CBS4 has a leading role in them. Besides the CBS-related variables, DSET-related-variables have main role in determining CBS with respect to all types of variables.

DISCUSSION

This study examined mathematics teachers' perceived skill transformation in online pedagogical practices through digital technology during the COVID-19 pandemic. Their perceived skill transformations were measured under five dimensions: PCUT, students' communication behaviors, CST, digital skill enhancement of teachers, and software skill enhancement of teachers.

The level of transformation was found to be low in all dimensions, which might be due to the mandatory online classes since the first phase of the COVID-19 pandemic without adequate planning and lack of teacher readiness with the required skills. Another reason could be that the participants in the research needed to be adequately trained in using digital tools for communication, collaboration, and student support in using digital tools. Even many of them might not have supporting digital devices with Internet access. However, these observations provide insight into all teachers who were practicing online, blended, and flipped learning regarding the required skills to transform teaching and learning activities into an online mode. Besides these results, level of transformation is significantly low in each item (based on the assumed population mean), except for frequently CBS with teachers online, and students can ask about any problems (content-related or not) with teachers without hesitation in online mode.

In item-wise analysis, the level of transformation was found to be low in the communication skills of teachers as compared to face-to-face classes, and this result indicated that teachers felt communication was easier in a face-to-face setting than in an online environment. Their perceived difficulty in communication could be related to the cost of online tools and Internet connectivity. There are varieties of techniques of communication in an online environment, but for effective communication, teachers should have knowledge of selecting and using different media that can be used effectively (Bates, 2019). It might be the reasons that either training was largely focused on how to deliver content to the students rather than the process of conveying ideas, mathematical knowledge, and information in a way that intended the objective of learning (Sukthankar et al., 2009) or teachers still preferred face-to-face classes, and they might be waiting for the end of the pandemic and were unwilling to stay online for a long time (Alawamleh et al., 2020). This finding also suggests that mathematics teachers' training about the use of digital technology in remote learning should focus on communication skills that may help them know the flaws in communication and use them in online contexts in a responsible manner (Alawamleh et al., 2020). The trainers should be well aware of identifying the contextual barriers and developing the communication skills of the teachers to mitigate some of these barriers to teaching mathematics or other disciplines in online mode (Ally & Prieto-Blazquez, 2014; Bansal & Dhananjay, 2014).

The result of teacher-to-teacher collaboration and the use of cloud-sharing applications indicated that the teachers might have less practice in using these applications, such as Google Drive and One Drive, to name a few. About 36% of mathematics teachers had a high sense of skill transformation in collaboration with other teachers or students. Among them, they considered that online classes were effective for learners who are shy in a face-to-face class, provided frequent, easy, and safe communication, and made it easy to share their quarries with the teachers. This result was consistent with the finding that asynchronous online discussion was more effective than face-to-face mode by Qiyun and Huay (2007). The level of mathematics teachers' perceived skill transformation in developing digital pedagogical skills through participation in online courses, collaboration, and self-practice was low. This finding is significant for teachers who have been conducting online classes (Caena & Redecker, 2019; Dore et al., 2015; Ottestad et al., 2014).

Additionally, this is an insightful finding for a government agency planning further digital skills training for mathematics and other teachers. Moreover, the finding also suggested that the mathematics teachers of Nepal considered the lockdown period an opportunity to develop digital pedagogical skills for themselves and their students (St-Onge et al., 2022). However, most have a low sense of digital skills transformations during online remote teaching. The study's findings also showed that only 37% of mathematics teachers' perceived skills transformation in learning was found to be high regarding the teachers who learned the applications of software by attending virtual training and online courses, watching tutorials, and studying the user guides of the applications, indicating that they were somehow busy learning novel practices of technological tools.

The digital transformation of teachers is significant in terms of collaboration skills, PCUT, and improving the communicative behavior of teachers. That means those teachers who were active in the digital world have developed the skills of communication and collaboration, which are crucial components of the online learning environment and 21st-century skills (CITE). Also, the contribution of the practice of communication tools to the overall digital transformation of female teachers was at the highest level, while the collaboration skills were at the lowest level for females. However, the similar contribution of the three skills enhancements on collaboration, PCUT, and the communicative behavior of students was also observed for male teachers (Henderikx et al., 2017). A similar case was also seen in public school teachers, while the communicative behavior of students has a significant contribution for institutional teachers.

The study showed varied results based on the independent variables of gender and type of institution. The positive association between the enhancement of teachers' digital skills and their software-using skills indicates that those teachers who can use subject-related software can eventually enhance their digital skills. Similarly, digital skills enhancement is necessary to handle software related to mathematics for all teachers, as argued by Lisbeth et al. (2019). The result shows that digital skills enhancement tools can improve PCUT.

More importantly, DSET can increase the use of communication tools to communicate with students and peers and improve CBS with peers and teachers, as Khalil et al. (2020) explained. However, only digital skills enhancement can improve CST, which need other skills as well, for example, techniques to use cloud services such as OneNote, Google Drive, etc. (Green et al., 2020). Those teachers who can handle the software for mathematics learning can have better collaboration skills, particularly female and public-school teachers. Similarly, the effect of software-use skills on using communication tools was significantly positive for female teachers and teachers from public institutions. However, the result was insignificant for the private institution teachers. That may be because of the opportunity provided to the private schools' teachers. Thus, equal opportunity should be provided to the teachers of private institutions in the process of producing digitally competent mathematics teachers.

Collaborating is one of the essential skills of twenty-first-century teachers and students. This study also shows that teachers with good collaboration skills also practice communication tools to communicate with students and peers. The skills of teachers to collaborate in an online environment also improve the communicative behavior of students. One more interesting result is that teachers using communication tools can also improve CBS. Thus, for better interaction between students and teachers in an online mode of education, teachers should use a variety of communication tools.

Hence, the concerned authorities in education should focus on improving teachers' communication and collaboration-related skills transformation because the significant focus and aim of education in each country are to change behavior of learners. Similarly, collaboration and communication-related skills transformation substantially affect teachers' digital skills. Hence, these skill transformations support integrating pedagogical and technological skills in the online classroom. Additionally, transformation in digital skills development and collaboration are the key factors to determine the learning support, and it indicates that teachers' collaboration and use of cloud storage devices and pedagogical and technological skills for online training and participation in online courses may support enhancing digital, pedagogical, and social skills development.

CONCLUSIONS

After the outbreak of COVID-19 in 2020 and 2021, all Nepalese educational institutions shifted teaching and learning activities into online mode without any preparation. Teachers, particularly in mathematics, have faced various challenges in conducting their teaching and learning activities in online mode. In the meantime, different organizations and teachers' associations conducted digital trainings and workshops to support mathematics teachers in developing their digital pedagogical skills. We (the authors of this article) also facilitated workshops and training sessions in 2020 and 2021 in collaboration with the teacher unions and professional organizations. Teachers' reactions after the series of workshops were found to be very encouraging. The teachers seemed to be empowered with new knowledge and skills to conduct online teaching and learning by using different online applications and tools during the lockdown periods in Nepal. However, there was limited information about mathematics teachers' skills transformation and its impact on their teaching practices. Therefore, we decided to conduct this study on how technology can transform the role of teachers and students' communication behavior in teaching and learning mathematics. The perceived skill transformation of teachers through technology was measured in five dimensions. PCUT, CBS, CST, DSET, and software skills enhancement of teachers. The level of transformations in all dimensions was found to be significantly low. Hence, additional digital pedagogy-related training and awareness among teachers are needed. The improvement in one dimension would also positively support other dimensions because the correlation between all dimensions was positive. Although correlation does not mean causation, it still shows the direction of change relative to each other.

PCUT, CST, DSET, and software skills enhancement of teachers are significant contributors to students' communication behaviors. Moreover, DSET and PCUT have a positive effect on CST, whereas the software skills enhancement of teachers was found to be the main contributor to determining the communication skills of mathematics teachers. This study also suggested that technology can be very influential in transforming teachers' roles and learners' communicative behaviors. The technology integration workshop and training organized by various organizations also seemed effective for the technological empowerment of mathematics teachers in Nepal during the COVID-19 pandemic.

Implications

This study has several implications for the teachers, educators, and policymakers directly or indirectly involved in the online learning system. Communication skills were particularly challenging for teachers in the online environment, highlighting the need for training programs that focus on effective online communication strategies. Collaboration among teachers and the use of cloud-sharing applications were also found to be areas, where improvement is needed. However, it is encouraging to note that some teachers recognized the benefits of online classes, such as facilitating communication with shy students and providing easy access to support. Education authorities should prioritize comprehensive training programs that address the specific needs of mathematics teachers in online pedagogical practices. These programs should include communication and collaboration skills development, as well as proficiency in using digital tools and software. Efforts should be made to ensure that teachers have access to necessary digital devices and reliable internet connectivity to effectively engage in online teaching. Adequate resources and support should be provided to bridge the digital divide among teachers. Collaboration and communication skills are crucial components of twenty-first-century skills. Efforts should be made to develop and enhance these skills among teachers, as they have a direct impact on student engagement, interaction, and learning outcomes in online environments. Policies should ensure equal opportunities for professional development and access to resources for teachers across different types of institutions, including public and private schools. Addressing any disparities in training and support can contribute to producing digitally competent mathematics teachers.

Limitations

Despite all the findings, this study has several limitations, which should be addressed in future research. First, the participants of the study were selected from a very small sampling frame by using email addresses provided by STFT and Council of Mathematics Education of Nepal. So, the generalizability of the study's findings might be limited to the population that is digitally competent and trained for remote online education. So, replication studies should be conducted in different contexts, levels, and disciplines. Second, the data for the study was collected only from mathematics teachers. This study suggests other similar studies involving students and other subject teachers, including school administration, to examine their role in transforming digitally appropriate pedagogy for equity and access to all learners. Further research is needed to identify and evaluate effective practices for online pedagogical practices in mathematics education. This research can inform the development of evidence-based guidelines and best practices for teachers and policymakers.

Author contributions: All authors were involved in concept, design, collection of data, interpretation, writing, and critically revising the article. All authors approved the final version of the article.

Funding: The authors received no financial support for the research and/or authorship of this article.

Ethics declaration: Authors declared that the study was approved by a higher education institution in Nepal. Informed consents were obtained from the participants.

Declaration of interest: Authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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