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Building inclusive learning environment through hybrid learning system: Role of technology and corresponding engagement

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ABSTRACT

The effective management with online resources has always been influential in hybrid learning systems, particularly in fostering inclusive learning environment. In this connection, this study examines the impact of technological infrastructure and preparedness to examine their effects on the perceived effectiveness of a hybrid learning system applying the Community of Inquiry (CoI) framework from quantitative aspects. Data were collected from university students in Pakistan using a questionnaire and analysed using a covariance-based structural equation model (CB-SEM). The results revealed that technological infrastructure has a significant positive relationship with conscious attention and affection while a positive but insignificant relationship with enthused participation and social connectedness. The relationship of preparedness with conscious attention, enthused participation, affection, and social connectedness was found significant and positive. The impact of conscious attention, enthused participation, and affection on perceived learning effectiveness was found to be positive and significant however, it was not significant in the case of social connectedness . The finding underscores the need for sufficient investment in technological infrastructure to create inclusive, resilient and high-quality learning environment. This way, the study contributes to the existing body of knowledge through examination of critical role of engagement with online resources in achieving impartial and quality hybrid learning system.

1. Introduction

Hybrid learning system is an education system which combines in-person traditional education system with online task completion [1]. According to Essa [2] and Kanetaki et al. [3], it allows flexibility in learning systems promoting sustainability with minimum use of physical infrastructure leveraging the use of technology infrastructure. Due to this ability, process of hybrid learning has been effective among developed parts of the world [4] while among developing nations, it enhances inclusive learning but its efficiency among developing countries is still undermined as highlighted by Jha and Ghatak [5]. As role of technology is primary in hybrid learning, a good technological infrastructure helps its users to engage effectively in hybrid learning system [6]. Infrastructure, comprising internet facilities and databases, helps in facilitating hybrid learning which ensures the seamless access to diverse set of resources with a sense of affiliation and social connectedness for effectiveness of hybrid learning [7,8].

Among developing countries, the necessary components of technological infrastructure are often inadequate, which results in less engagement with the system and consequently hampers perceived effective learning [9]. Given that a significant portion of teaching and learning activities in a hybrid learning system occurs online through a course website [10] which requires robust network components to facilitate communication and data transfer within and beyond the institutions [11–13]. This way, infrastructure reinforces supporting technologies crucial for the hybrid learning process, such as internet connectivity and speed [14].

Existing studies have established a link between technological

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infrastructure and technology preparedness which shows that good infrastructure help its users to be prepared for a new system in an effective way [15,16]. The positive integration of technology infrastructure and preparedness helps technology users to engage with the learning system to derive maximum productivity [17]. Unfortunately, internet connectivity in developing counters remains inadequate which discourage students to interestingly take part in an online learning system [18,19]. This way, it is evident that technological infrastructure associated with technological preparedness affects the engagement of students in a hybrid learning system and distortion among technological infrastructure and preparedness can affect the perceived learning effectiveness among the students in developing countries.

Context to this relationship, we conducted a profound review of existing studies and found that existing literature lacks in examining the relationship between technology infrastructure (TINF), technological preparedness (TPRE) and engagement in online resources for learning effectiveness among university students [20–22]. Specifically, these concepts mostly have been examined using qualitative or mixed-method research approaches [23,24], which emerges the need of literature from this perspective.

Given the above situation, this study explores the intricate relationship between technological infrastructure, technology preparedness, and students' engagement with online resources within the framework of hybrid learning systems. By examining these factors, it seeks to uncover how dimensions of online engagement with online resources affects university students' learning effectiveness through hybrid learning systems. Furthermore, it provides quantitative evidence to support the existing understanding of Community of Inquiry (CoI) offering insights that how inclusive learning can be promoted through hybrid learning system. For this purpose, this study applied a rigorous quantitative analysis techniques collecting data from Pakistan considering current technological infrastructure and growing need for hybrid learning system. By addressing these concerns, this study make substantive contributions to the literature on hybrid learning by filling a critical gap in understanding the interplay between the technological infrastructure, student engagement and technological preparedness of developing countries [25]. Unlike most of the previous studies focusing on qualitative, mixed-method approaches or frameworks such as technology acceptance [26,27], this study adopts purely a quantitative perspective offering clarity in analyzing the factors related to hybrid learning's effectiveness. It further brings solution to the challenges faced by hybrid learning in developing countries face in the form of intermittent internet connectivity and poor technological infrastructure as highlighted by Zarei and Mohammadi [28]. Thus, this study not only enrich theoretical understanding on the subject matter but also provides actionable recommendations for policymakers and institutions. It underscores the need for overcoming the technological barriers in under-resourced environment contributing to the inclusive learning through equitable and effective hybrid learning system.

In the following section, theoretical underpinning of study has been provided followed by the hypothesis development in light of a brief literature review. Further, methodology adopted for this study has been discussed followed by the results and analysis. In later parts, discussion of results and conclusion have been provided considering the limitations of this study for future research endeavours in hybrid learning at university level.

2. Theoretical development

From a didactic perspective, the Technology Acceptance Model (TAM) provides valuable understandings of the technology acceptance, particularly within hybrid learning systems. Initially proposed by Davis [29], TAM explains the processes through which users adopt and utilize a new technological system. Following the TAM, the Community of Inquiry (CoI) framework, initiated by Garrison et al. [30] and Anderson et al. [31], underscores the significance of three interconnected components related to the hybrid learning that are cognitive presence, social presence, and teachers' presence. CoI framework describes that cognitive presence is an effect extent to which learners derive meanings through sustained reflection and discourse of the learning system, necessitating conscious attention. Technology infrastructure and preparedness assume to have pivotal role in facilitating cognitive presence by furnishing reliable access to learning materials, tools, and platforms conducive to active engagement and critical inquiry [32]. Meanwhile, social presence, intricately linked with affection and enthused participation, maintaining the perceived sociability and interpersonal connection among participants in the form of affection and social connectedness.

The CoI framework underscore the importance of physical, cognitive, social belongingness while TAM helps to perceive maximum benefits from technology usage. Hence, integration of CoI framework with TAM can help student, teachers and institutions for effective practices through adopting hybrid learning systems conducive for engagement with online resources. Extending this understanding, this study used technology infrastructure (TINF) and technology preparedness (TPRE) as independent variables to see their causal relationship with four dimensions; conscious attention, enthused participation (EEP), affection (EAF) and social connectedness (ESC). Later impact of each dimension has been examined on perceived learning effectiveness (PEL) of hybrid learning system as given in Fig. 1.

Fig. 1 displays TINF and TPRE along with their respective effect dimensions to the PEL, taking in the different engagement dimensions with online resources considering existing literature. TINF through the tools and systems elevates students' levels of Conscious Attention (ECA) (H1), Enthused Participation (EEP) (H2), Affection (EAF) (H3) and Social Connectedness (H4), thus enabling productive interactions over the digital platforms. Similarly, TPRE, reflecting readiness and competence, strengthens ECA (H5), EEP (H6), EAF (H7), and Social Connectedness (ESC) (H8), which can facilitate the navigation of online learning environments. These engagement dimensions mediate the relationship between technological factors and PEL. ECA (H9), EEP (H10), EAF (H11), and ESC (H12) influence students' perception of learning success. Overall, this framework emphasizes how robust technology and readiness cultivate meaningful engagement with online learning, which drives effective learning.

3. Literature review

3.1. Technological infrastructure

A robust infrastructure supports diverse learning approaches, including hybrid learning, flipped classrooms, and adaptive learning platforms, and tailored to individual learner needs and preferences [33–35]. Several investigations highlighted the important role of vigorous TINF in facilitating online learning engagement [36]. Online engagement encompasses active participation, collaboration, interaction, and progress monitoring within hybrid learning systems [37–39]. Subsequently, robust infrastructure with the integration of TPRE serves as a catalyst for fostering meaningful engagement in the form of ESC and EEP [40]. This way, students' engagement leads this process towards effectiveness of hybrid learning by providing reliable connectivity, user-friendly interfaces, and multimedia resources.

Studies found that poor internet connectivity and unfulfillment of learning objective can distract students to be engaged in hybrid learning [41–43]. At this stage, good infrastructure helps the hybrid learning systems to keep students engaged as they feel socially connected with peers and teachers [44]. Hanaysha et al. [45] conducted a study to see the impact of university facilitates and technology resources on students' engagement and educational performance among Arab students. They found that technology resources positively student engagement in their studies for higher educational performance. Extending this debate, it was also found that infrastructure supports technology users in a

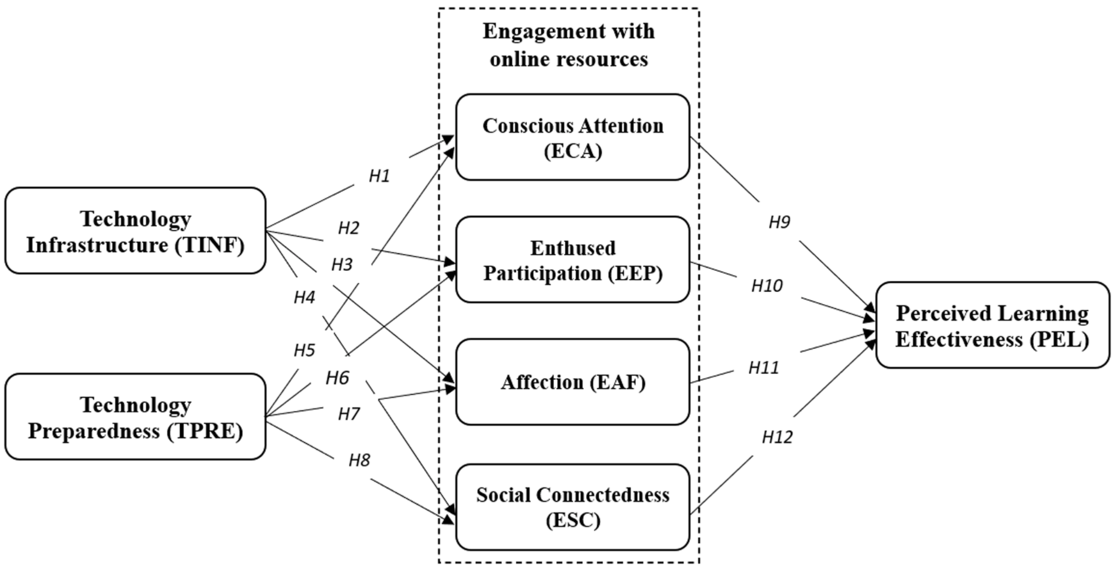

Fig. 1. The conceptual model.

positive way and, simultaneously, is important for effectiveness of hybrid learning as endorsed by Goodyear [46]. Hence, this study posits that.

H1. *TINF is positively associated with ECA for engagement with online resources during hybrid learning system.*

H2. *TINF is positively associated with EEP for engagement with online resources during hybrid learning system.*

H3. *TINF is positively associated with EAF for engagement with online resources during hybrid learning system.*

H4. *TINF is positively associated with ESC for engagement with online resources during hybrid learning systems.*

3.2. Technology preparedness

As discussed above, good infrastructure helps users of a new system to be prepared so that they can derive maximum benefits from its use. According to a report published by Organisation for Economic Co-operation and Development (OECD) [47], technology preparedness (TPRE) is a state of affairs when a technology user has become capable of effectively adapting to use a technological system addressing its challenges and opportunities. In addition, it has an association with infrastructure and resources which keep technology users engaged in utilizing a technological system like hybrid learning systems [48]. Several studies explored online teaching and learning at school and college-level study settings during the pandemic considering teachers' level of preparedness and learning effectiveness in hybrid learning systems. For example, Webb et al. [49] surveyed college teachers to examine their preparedness for online engagement towards effective learning. The authors found that those teachers were positively determined and prepared themselves to embrace technology for enhanced learning. Kirshner [50] investigated the transition to radio-based education considering the internet connectivity issues and revealed challenges in adapting to the new system without the fullest engagement of teachers that affects the connection and learning from students' perspective. In addition, this distortion in the student-teacher relationship may lead to lower affection among the two characters as noted by Yao et al. [32]. Increased online communication between teachers, students and peers positively influenced student social connection in facilitating effective online education. In view of this discussion, we postulate that.

H5. *TPRE is positively associated with ECA for engagement with online resources during hybrid learning systems.*

H6. *TPRE is positively associated with EEP for engagement with online resources during hybrid learning systems.*

H7. *TPRE is positively associated with EAF for engagement with online resources during hybrid learning systems.*

H8. *TPRE is positively associated with ESC for engagement with online resources during hybrid learning systems.*

3.3. Engagement with online resources

Engaging students with online resources involves more than just attending lectures or completing tasks; involving a deep sense of integration with the digital platform, allowing users to get maximum benefits from the system [51,52]. Studies suggest that establishing a connection with educational programs, teachers, and peers significantly influences academic success at college level education [53,54]. This active engagement turns into the higher academic achievement and progress, irrespective of the learning environment, either it is traditional or online which was noted by Bond et al. [55]. In hybrid learning, students who feel engaged and connected, fostering a strong sense of belonging, typically invest more effort in their learning activities [10, 12].

University students, being adults, require nurturing relationships and meaningful social connections. However, they also face numerous problems such as excessive reliance on technology and digital disparities, which can impede their engagement with technology in pursuit of effective learning [56]. Historically, Vivek et al. [27] have outlined four critical aspects that captivate technology users: (1) Conscious Attention, (2) Affection, (3) Enthused Participation and (4), Social Connection. Previous studies have highlighted the importance of stable internet connection, which comes from good infrastructure, in keeping students actively engaged throughout the learning process [57,58]. A study conducted by St Clair et al. [24] explored the effect of conscious attention towards learning effectiveness through the use of AI in education. The authors found that stable channels cause conscious attention towards effective learning using technology. Van Esch et al. [8] spearheaded a study examining the role of conscious attention, social connection and enthused participation in learning effectiveness through qualitative data collected from American university marketing students. They found the positive role of conscious attention, social connection and enthused participation is positive and significant in learning effectiveness while learning through online media. In a recent past, Van der Rijst et al. [59] found that effective learning process can be influenced by sense of integrity and social connections. Applying this concept in hybrid learning systems, we have developed the following hypotheses to evaluate the impact of engagement with online resources.

H9. *ECA positively affects the perceived learning effectiveness (PLE) of hybrid learning systems.*

H10. *EEP level positively affects the perceived learning effectiveness (PLE) of hybrid learning systems.*

H11. *EAF positively affects the perceived learning effectiveness (PLE) of hybrid learning systems.*

H12. *ESC during hybrid learning positively affects perceived learning effectiveness (PLE) of hybrid learning systems.*

4. Research methods

4.1. Instrument development

This study employed an adapted questionnaire on technological infrastructure, sourced from OECD policy reports [47], tailored for hybrid learning. Other items of the variables had also been adapted from existing studies which, along with their factor loadings, have been presented in Appendix-1. The questionnaire of the study was composed of three sections: demographic information, confirmation of hybrid learning awareness followed by main questions of the variables. It is important to mention that responses were rated on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The table shows that factor loading of all the items found greater than 0.5 which shows factors are correlated with variables and have no issue of validity of the construct with the current method [60].

4.2. Participants of the study

To ensure factor stability with the method applied, a large sample size (usually greater than 200) is recommended [61]) hence, we sent 900 Google Form links to the students enrolled in undergraduate and graduate degree programs[1] in HEIs in Central Punjab, Pakistan employing snowball sampling technique through our peers working in the HEIs [36]). Before beginning the main questionnaire, all participants were asked to provide informed consent, confirming their experience with the hybrid learning system to ensure the quality and relevance of the data collected. Hence, out of the 900 invitations, a total of 421 responses were received back and, after data screening, 393 responses were found valid and fit for final analysis.

Table 1 describes the gender and age details of the respondents. The female respondents dominate with a 64.6 % (254 out 393) while male respondents are 139 with 35.4 %. Further, 61 (15.5 %) of the respondents are less than 25 years while 113 respondents (28.8 %) were found between 35 and 45 of age enrolled in degree programmes. Majority of the respondents (44.4 %) were found between the age group 25 and 35 years. The demographics of the student also showed diversity in age as some student found over 45 years of age.

[1] In Pakistan, degree programs include bachelor (BS (Hons.), Master and PhD program after BS (Hons.). Source: Higher Education Commission's National Qualification Framework.

Table 1
Demographic details of the respondents.

		Frequency	Percentage
Gender			
	Male	139	35.4
	Female	254	64.6
	Total	**393**	**100.0**
Age			
	Less than 25 years	61	15.5
	25–35 years	176	44.8
	35–45 years	113	28.8
	Above 45 years	43	10.9
	Total	**393**	**100.0**

4.3. Analysis procedure

Given the study's objectives and identified research gap, data were collected from the university students who were known to hybrid learning. Using engaged university students from Pakistan. Following preliminary analysis, which addressed issues such as missing values and outliers, the reliability of the constructs was assessed. This process ensured that the data were suitable for conducting structural equation model (SEM) using Smart PLS4, employing an adapted scale [38,62]. Before running CB-SEM, this study examined measurement model through the software to assess the model fit indices so that robust and reliable results from the CB-SEM can be obtained which allows researchers to simultaneously examine relationships and effects among observed and latent variables while evaluating the model's goodness-of-fit and testing complex hypotheses [61]. As this study used random probability sampling technique, the analysis was run using 5000 bootstraps at a 95 % confidence level to estimate the sampling distribution.

5. Results and analysis

5.1. Results of the measurement model

As discussed earlier, this study ran confirmatory factor analysis (CFA) before path analysis for hypothesis testing. The results of full model run presented that chi-square of estimated model is significant at $p < 0.05$ but, as it purely depends upon the sample size as suggested by [61], there is no issue with the model fit with root mean square error approximation (RMSEA) was less than the criteria 0.08 as shown by Table 2 below.

The absolute fit indices like good of fit (GFI), adjusted goodness of fit (AGFI), and standardized root mean square residual (SRMR) all found

Table 2
Model fit indices.

	Model-Fit Index	Acceptance Level	Obtained Results
1. Absolute Fit	Chi-square of the estimated model	$p < 0.05$	0.000
	RMSEA	< 0.08	0.063
	GFI	> 0.90	0.912
	AGFI	> 0.90	0.875
	SRMR	< 0.05	0.047
2. Incremental Fit	CFI	> 0.90	0.896
	TLI	> 0.90	0.907
	NFI	> 0.90	0.896
3. Parsimonious Fit	$\chi 2$/df	< 3.00	2.560

Note: GFI = goodness of fit index, RMSEA = root mean square error of approximation, AGFI = adjusted goodness of fit index, SRMR = standardized root mean-square residual, TLI = Tucker-Lewis's index, CFI = comparative fit index, and NFI = normed fit index.

greater than 0.5 [63] or near to 0.90 which means the model is absolutely fit for analysis. Other criterion like comparative fit indices, Tucker-Lewis Index (TLI) and normed fit index (NFI) were also found less than 0.90 criteria ideal for running the analysis through SEM. The value of $\chi2/df$ for parsimonious fit was also found less than 3.00 criteria (see Table 2). Hence, the model has no issue and fit to run the SEM for hypothesis testing.

Considering the shortfalls of existing studies in the hybrid learnings, Table 3 presents the reliability and validity through CB-SEM showing the values of Cronbach's alpha (CA), composite reliability (CR), the average variance extracted (AVE), and heterotrait-monotrait (HTMT) ratios [64]. The table shows that values of Cronbach's alpha for each variable were found greater than 0.70 confirming the reliability of the constructs while values CR also found greater than threshold value [65, 66]. Further, AVE for discriminant validity ranges from 0.51 to 0.88 (greater than 0.50) confirming that constructs are valid. The values of HTMT ratios were also found less than 0.85 which shows that the constructs are valid for reliable and robust results in line with the suggestions of Henseler et al. [45].

5.2. Results of path analysis

The results of the structural path analysis are presented in Table 4. They indicate that TINF significantly influences ECA ($\beta = 0.184$, $t = 2.555$, $p = 0.05$) and EAF ($\beta = 0.260$, $t = 5.035$, $p < 0.05$), thereby supporting Hypotheses H1 and H2. These findings suggest that a robust technological infrastructure positively enhances students' conscious attention and academic affection in hybrid learning environments. However, TINF did not exhibit a statistically significant impact on EEP ($\beta = 0.072$, $t = 1.144$, $p > 0.05$) or ESC ($\beta = 0.048$, $t = 1.180$, $p > 0.05$), leading to the rejection of Hypotheses H3 and H4. This implies that infrastructure alone may not be sufficient to foster students' enthusiasm or social engagement through online learning resources.

The analysis further reveals significant positive relationships between TPRE and all four dimensions of engagement with online resources. Specifically, TPRE has a strong and statistically significant effect on ECA ($\beta = 0.227$, SE $= 0.036$, $t = 4.618$, $p < 0.001$), thus supporting H5. Likewise, TPRE is positively associated with EEP ($\beta = 0.216$, SE $= 0.043$, $t = 4.384$, $p < 0.001$), confirming support for H6. Additionally, TPRE demonstrates a modest but significant effect on EAF ($\beta = 0.074$, SE $= 0.020$, $t = 2.472$, $p < 0.05$), and a similar positive impact on ESC ($\beta = 0.078$, SE $= 0.024$, $t = 3.555$, $p < 0.05$), thereby supporting H7 and H8 of the study.

Regarding the influence of engagement dimensions on PEL, both ECA and EAF have significant and positive impacts on PEL ($\beta = 0.426$, $t = 3.750$, $p < 0.01$ and $\beta = 0.474$, $t = 3.236$, $p = 0.001$, respectively), confirming that these dimensions play crucial roles in students' perception of effective learning. EEP shows a positive but weak yet meaningful impact ($\beta = 0.048$, $t = 1.478$, $p = 0.070$), while ESC was not significantly related to PEL ($\beta = 0.044$, $t = 0.814$, $p = 0.208$), implying that social connectedness may not directly influence students' learning outcomes in this hybrid context. This suggests that students may feel isolated while acquiring knowledge through hybrid learning systems.

Overall, the results emphasize the importance of technology preparedness in fostering multiple forms of engagement and underscore that conscious and affective engagement are critical mediators between technology factors and effective learning outcomes in hybrid learning systems.

6. Discussion and conclusion

Extending discussion from the previous section, H1 and H3 for a significant relationship of infrastructure with conscientious attention, and affection have been accepted at $p < 0.01$ while its impact on enthused participation and social connectedness that have not been proved true rejecting H2 and H4 as $p > 0.10$. The results show that good technological infrastructure affects university students' engagement with online learning systems but at the same time, student feel socially disconnected which effect their enthused participation for effectiveness of hybrid learning system. These varied results partially agreed with the existing studies that found significant impact of technological infrastructure on engagement with online learning [1,67,68]. For the impact of technological preparedness, the results confirm acceptance of H5, H6, H7 and H8 of this study help us to postulate that technologically well-prepared university students were found more engaged with the online resources. As this concept describes the user's propensity to the adopted technology so, the university students seem to have greater propensity to be engaged with online learning. This way results the study contradict with the results of the study of Kirshner [50] in context of technology preparedness and engagement with online resources. The individualistic impact of dimensions of engagement with online resources for hybrid learning directs postulate that except social connectedness, other three dimensions play important role in perceived learning effectiveness of hybrid learning among university students. The study conducted by Caulfield [10] found that students, through technology, feel connected while this study results contradict with his study which may be due to the poor technology infrastructure and intermittent internet connection which negatively influence engagement of the students with online resources for hybrid learning system.

Learning system has been undergone through significant changes for last two decades [26]. Especially, spread of COVID-19 totally changed the pedagogical management which forced HEIs management to go for alternative ways. Although hybrid learning system was already in practice to facilitate those students who were unable to full attend their institute due to some reasons like; remote areas, lack of sufficient funds, travelling difficulties and many more. The popularity of hybrid learning systems has been widespread for last four years and HEIs have continuously practicing it due to its sustainable characteristics [69]. The effectiveness of hybrid learning systems has been hampered as developing parts of the world do not have good infrastructure like internet connection stability and the stakeholders of hybrid learning system do not get them prepared. This way, the effectiveness of this learning system has not been flourished in the course of sustainable development. This study intended to examine this situation considering technology infrastructure along with preparedness to assess their relationship with online engagement. Results revealed that technological infrastructure has positively associated with engagement of students with online resources during involvement in hybrid learning systems. Specifically,

Table 3
Results of reliability and validity.

	Construct	CA	CR	AVE	1	2	3	4	5	6	7
1	**Technology Infrastructure**	0.82	0.83	0.56							
2	**Technology Preparedness**	0.93	0.94	0.76	0.24						
3	**Affiliation**	0.76	0.86	0.61	0.62	0.19					
4	**Conscious Attention**	0.78	0.71	0.53	0.32	0.29	0.58				
5	**Enthused Participation**	0.78	0.80	0.51	0.10	0.27	0.15	0.18			
6	**Social Connection**	0.75	0.78	0.58	0.09	0.11	0.13	0.14	0.09		
7	**Perceived Learning**	0.86	0.88	0.56	0.21	0.26	0.58	0.50	0.16	0.11	

Note: CA: Cronbach's alpha, CR= composite reliability, and AVE= average variance extracted.

Table 4
Results of the path analysis.

Relationship	Hypothesis	Estimates	SD	T stat.	P values	Decision
TINF -> ECA	H1	0.184	0.070	2.555	0.005	Supported
TINF -> EEP	H2	0.072	0.061	1.144	0.126	Not Supported
TINF -> EAF	H3	0.260	0.052	5.035	0.000	Supported
TINF -> ESC	H4	0.048	0.039	1.180	0.119	Not Supported
TPRE -> ECA	H5	0.227	0.036	4.618	0.000	Supported
TPRE -> EEP	H6	0.216	0.043	4.384	0.000	Supported
TPRE -> EAF	H7	0.074	0.020	2.472	0.042	Supported
TPRE -> ESC	H8	0.078	0.024	3.555	0.021	Supported
ECA -> PEL	H9	0.426	0.112	3.750	0.000	Supported
EEP -> PEL	H10	0.048	0.033	1.478	0.070	Supported
EAF -> PEL	H11	0.474	0.144	3.236	0.001	Supported
ESC -> PEL	H12	0.044	0.054	0.814	0.208	Not Supported

Source: Smart PLS4 output.
Notes: TINF= technological infrastructure, TPRE= preparedness, ECA= conscious attention, EAF= affiliation, EEP= enthused participation, ESC= social connectedness, and PEL= perceived effective learning.

conscious attention, enthused participation, affection, and social connectedness have been strongly associated with good infrastructure, are in line with the previous studies [10,51]. We applied preparedness as exogenous factor to examine it association with engagement with online resources and results state no relationship of preparedness with conscious attention, enthused participation, affection, and social connectedness. The novel application of preparedness as exogenous variables with infrastructure deviates from results of the existing studies. This way, it confirms the application of CoI framework from teaching, social and cognitive perspective among developing countries when it backed by technology infrastructure in line with the findings of Morueta et al. [39]. Decisively, the engagement of teachers, administration and students is closely associated with good infrastructure.

The results of CB-SEM for examination of the impact of dimension of engagement with online resources provides mixed understandings. Impact of EAF and ESC on PEL has been insignificant which rejects the results of existing studies [58,8]. From this, the comprehension about the social needs of university students has been evident theoretically stands true. For other two dimensions, ECA and EEP, it has been observed that students at HEIs are determined towards their studies as these two dimensions positively and significantly impact PEL of the students in line with the study of Van der Rijst et al. [59]. These results help us to develop a comprehension that university student consider hybrid learning effective during learning process but show concerns related to affiliation and social connectedness during the hybrid learning systems [24]. This situation confirms the conventional models highlighted by Carrillo and Flores [70] and Singh et al. [19] related to the significance of individual factors in shaping attitudes, contradicting previous findings related to teachers' perception during Covid-19.

6.1. Implications of the study

This study contributes both theoretically and practically to the understanding of hybrid learning, especially in the context of developing countries. It applies the Community of Inquiry (CoI) framework, focusing on four key dimensions of student engagement in online learning, through a fresh and proactive approach. Using CB-SEM with a 95 % confidence interval and 5000 bootstraps, twelve hypotheses were tested, and nine were supported as shown in Table 4. The results are robust and reliable, providing valuable insights relevant to hybrid learning in today's digital landscape.

6.1.1. Theoretical implications

This study contributes to existing literature by applying the CoI framework in a novel and proactive way to hybrid learning systems, specifically within the context of developing countries like Pakistan. The validation of nine out of twelve hypotheses using CB-SEM @5000 bootstraps confirms the robustness and relevance of the framework in explaining meaningful student engagement in hybrid learning systems. Unlike traditional Technology Acceptance Model (TAM) approaches, which a focus on behavioral factors, this research underscores the importance of cognitive and social presence aligned with the model as highlighted by Garrison et al. [11], but extending theoretical understanding of engagement with technology (i.e., online resources) beyond individual behavior to social and contextual dimensions. Most existing studies on hybrid learning have been conducted using qualitative or mixed-method approaches. This study applied a quantitative approach in CoI framework context using stringent quality checks such as Cronbach's alpha, AVE, and HTMT. This way, it establishes a reliable methodological contribution, encouraging future quantitative research in the field of hybrid learning systems.

6.1.2. Practical implications

The findings also have important practical implications for HEIs and policymakers, particularly in developing countries facing infrastructural challenges. The institutions in developed nations are rapidly switching towards online modes of learning and, the interruption of internet connectively caused form poor infrastructure affects students' engagement with online learning modes. Student unable to pay due attention, specifically fearing a loss of social connectedness, cannot create balance between affiliation with their teachers and peers. The study highlights that technology infrastructure and preparedness are critical drivers of student engagement and effective hybrid learning, often outweighing the quality of course content itself. This insight urges policymakers to prioritize investments in stable internet connectivity and electricity supply to ensure uninterrupted learning experiences. The results also emphasize the necessity for HEIs to address infrastructural weaknesses to foster student connectedness with peers and instructors, which are essential for inclusive and effective learning. By recognizing these practical barriers and the social dimensions of engagement outlined by the CoI framework, educational institutions can design targeted interventions and resource allocations to enhance the hybrid learning systems optimizing the benefits of technology.

6.2. Conclusion

Through the examination of the technological aspects aimed at fostering an extended learning experience within the CoI framework, this study has effectively achieved its objectives by extending the applicability of the CoI framework in quantitative research. Furthermore, our findings provide valuable insights for prospective studies, urging them to recognize and adopt this novel approach within online educational management, particularly in the context of hybrid learning systems, amid the growing application of technology.

Our methodological approach encompassed the collection of cross-sectional data from university students engaged in hybrid learning systems, thereby laying the groundwork for robust and empirically validated results. To further enrich the depth of understanding, future investigations could employ longitudinal data collection methodologies within specific disciplines such as computer science, engineering, or social sciences, or even conduct comparative analyses. Such an approach facilitates the comparison of results across disciplines, enabling the examination of pre- and post-execution responses fostering a meaningful comprehension of behavioral dynamics over time towards online learning system. By adopting this methodology, the original conceptualization of hybrid learning systems, encompassing infrastructure and engagement with online resources, can serve as a foundational model for assessing the efficacy of hybrid learning systems. This, in turn, can contribute significantly for successful implications of innovative technologies to promote inclusive learning.

Ethical considerations

The study was conducted following the ethical standards laid down in the Helsinki Declaration, 1964 and later amendments.

CRediT authorship contribution statement

Yasser Arfat: Data curation, Conceptualization. **Muhammad Khalid Shahid:** Writing – original draft, Formal analysis. **Raed Saud Al-tayyar:** Writing – original draft, Investigation. **Khalid Mahmood:** Supervision. **Ahmed Alghamdi:** Writing – original draft.

Declaration of competing interest

The authors declare no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2025.100887.

Data availability

Data will be made available on request.

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