Collaborative Learning in the Edu-Metaverse Era: An Empirical Study on the Enabling Technologies

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***Abstract*—Computer-supported collaborative learning aims to use information technologies to support collaborative knowledge construction by practicing the relevant pedagogical approaches, especially in the distance learning setting. The enabling technologies are fast advancing, and the need for solutions during the COVID-19 global pandemic led to the emergence of the Edu-Metaverse, which is conceptualized as a collection of networked virtual worlds (i.e., the Metaverse) for learning. There is a great necessity to investigate how these more recent enabling technologies can support collaborative learning. This empirical study aims to collect both quantitative and qualitative results to fill the knowledge gaps. Specifically, 20 undergraduate students (three females and 17 males) taking the Game Design and Development course voluntarily participated in this study. The participants used three representative collaboration platforms (i.e., AltSpace, Gather, and ZOOM) in our laboratory for discussing three course-specific topics, simulating the undertaking of collaborative learning tasks in the distance learning setting. The results suggest that the participants were more engaged in the learning activities using the Metaverse platforms that offer avatar-mediated communications and collaborations (i.e., AltSpace and Gather). These platforms also gave the participants a stronger sense of copresence and belonging to the learning community. Potential improvements to the usability and the participants' feedback are also discussed in the article. We hope the results can contribute to the fast-growing use of the Metaverse-enabling technologies for educational purposes.**

***Index Terms*—Education, educational technology, hybrid learning.**

I. Introduction

COMPUTER-SUPPORTED collaborative learning (CSCL) aims to use information technologies to support collaborative knowledge construction [1]. Since the outbreak of the COVID-19 global pandemic, practicing CSCL in the distance learning setting has become more common at all education levels. At the same time, the advancement of the enabling technologies for CSCL, primarily virtual reality [2] and collaborative virtual environments [3], leads to the emergence of the concept of the Edu-Metaverse—a collection of networked virtual worlds (i.e., the Metaverse) for learning [4], [5]. Unlike conventional video conferencing, the communications among users are mediated by their avatars inside these virtual worlds [6]. The avatars are the digital representations of the users. They can convey more social cues (e.g., facial expressions and postures) if the necessary enabling technologies are in place [7], [8], [9].

Although empirical evidence suggests that socialization and remote collaboration can benefit from the aforementioned features and uniqueness of the Metaverse [8], [9], how the Metaverse platforms and the enabling technologies support collaborative learning needs to be further explored. One key question that practitioners may care about the most is whether learners can be more engaged in collaborative learning when supported by the Metaverse platforms in the distance learning setting.

Answering this question is challenging since it is simply impossible to investigate all existing platforms and technologies in one study. To select the representative platforms for investigation, we formalized the differences among different platforms from the perspective of avatar-mediated communication research. The differences can be systematically categorized into the following two dimensions:

1) the perspective of perceiving interpersonal activities between avatars (i.e., from a third-person or first-person perspective);
2) the immersion of the enabling technologies [10].

Based on this approach, we selected AltSpace[1] and Gather[2] as the two platforms that represent various existing Metaverse platforms. Specifically, AltSpace allows its users to engage in interpersonal activities in virtual spaces from the first-person perspective. At the same time, Gather only supports the top-down third-person perspective. Also, users can access AltSpace through head-mounted displays (HMD) but can only access Gather using conventional computer monitors. It is also interesting that Gather allows users to turn ON their webcams while engaging in avatar-mediated communications—a blend of

[1] [Online]. Available: https://altvr.com/
[2] [Online]. Available: https://www.gather.town/

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conventional video conferencing and avatar-mediated communications in the Metaverse era, although how the blending could affect users cognitively or psychologically is largely unknown. This difference may significantly impact the learners' sense of copresence in the virtual worlds and the learning experience as suggested in previous studies [6], [11]. Hence, selecting these two platforms is expected to help generalize the study's findings to a broader context of using the Edu-Metaverse for collaborative learning in the distance learning setting. Finally, ZOOM,[3] a conventional video conferencing platform that has been widely used for distance learning, was selected to serve as the control condition of this empirical study. In terms of the additional functionality to support collaborative learning, both Gather and ZOOM are more advanced than AltSpace. For example, Gather and ZOOM support text chatting, shared whiteboard, and file sharing. Although it is possible to have similar functions in AltSpace with the help of its built-in browser and external tools (e.g., Google Docs[4]), AltSpace has the most limited set of functions for collaborative learning.

The major contributions of this study include the following:

1) this empirical study explores how the Metaverse technologies can be applied for collaborative learning in the distance learning setting, which is currently underexplored;
2) the study uses both the subjective and objective data (i.e., the behavioral data depicting the participants' conversational activities when completing the collaborative learning tasks) to compare three representative platforms, from which the findings and implications can be generalized to a broader context of using the Edu-Metaverse for collaborative learning in the distance learning setting;
3) by applying the 4C model [12], potential improvements to the enabling technologies of the Edu-Metaverse are proposed based on the data analysis results, the course instructors' observations, and qualitative feedback from the participants.

II. Related Work

A. Computer-Supported Collaborative Learning (CSCL)

CSCL aims to improve learning by using information technologies to support collaborative knowledge construction [1]. There are three major categories of enabling technologies that have been studied in prior publications, including video conferencing tools, learning management systems (LMSs), and platforms for remote collaborations, which may not originally designed for collaborative learning [13], [14], [15], [16], [17], [18], [19], [20], [21], [22]. Video conferencing tools (e.g., ZOOM and Microsoft Teams[5]) have a clear emphasis on enabling real-time communications among learners and instructors; prior studies have also investigated the use of video conference tools for collaborative learning, especially during the global pandemic (e.g., [23], [24], and [25]). LMSs (e.g. Blackboard[6] and Canvas[7]) are often designed as web-based platforms for managing, delivering, and tracking educational content and programs [26]. Some social networks have also been used as LMS in prior studies (e.g., Facebook[8] groups in [27]). Similarly, platforms for remote collaborations, such as Miro,[9] which may not have been originally designed for collaborative learning, have also been adapted for collaborative learning recently. Through these platforms, learners can easily use web browsers for quickly exchanging information, sharing ideas and learning materials, managing group project progress, and visual-aided discussing with each other, which effectively enhances the continuity and efficiency of collaborative learning [17]. In recent years, the boundaries of the aforementioned three categories of enabling technologies have become more blurry. The emergence of the concept of the Edu-Metaverse also brings more possibilities to CSCL (see Section II-C).

B. Social Presence, Copresence, and Learner Engagement

In the context of CSCL in the distance learning setting, the term "distance" not only represents the geographical distances among learners and instructors but also indicates the psychological distance [28], [29]. As a result, social presence is regarded as a particularly critical factor of social communications in CSCL since it primarily reflects the psychological distance among peer learners and between instructors and learners, as perceived by each participant of CSCL [29].

The term social presence was first introduced by Short et al. [30, p.65] as "the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships." It overcame the shortage of the classical definition of the sense of presence in virtual worlds that ignores social interactions commonly seen in the Metaverse and Edu-Metaverse nowadays. During past decades, many researchers have worked on defining social presence. In this article, we follow the definition by Oh et al. [31, p.1] that social presence is referred to as the subjective experience of being there (i.e., in the virtual worlds) with a "real" person and "having access to his or her thoughts and emotions." Note that the definitions of copresence and social presence largely overlap [32], [33]. Hence, they will be synonyms and share meanings in this article. Previous empirical studies demonstrated that learners' perceptions of collaborative learning are positively correlated with their perceived social presence [34]. Hence, in this study, we used copresence as a key construct to measure participants' perceptions and experiences of collaborative learning.

Social presence and copresence have been suggested as potential influences on learner engagement and overall learning experience in the distant learning setting [35], [36]. In the context of learning in the Metaverse or Edu-Metaverse, it is postulated that the social nature of such multiuser virtual environments, which fosters a greater sense of social presence and copresence compared to other media for real-time social communications, can enhance learner engagement [35], [37]. This is because by

[3][Online]. Available: https://zoom.us/
[4][Online]. Available: https://www.google.com/docs/about/
[5][Online]. Available: https://www.microsoft.com/microsoft-teams
[6][Online]. Available: https://www.blackboard.com/
[7][Online]. Available: https://www.instructure.com/canvas
[8][Online]. Available: https://www.facebook.com/
[9][Online]. Available: https://miro.com/

creating meaningful and interactive social spaces, the Metaverse and Edu-Metaverse can reduce the psychological distance and induce a sense of belonging among learners, thus promoting more active participation. Encouragingly, recent studies have provided some preliminary evidence to support this theoretical claim, showing that high social presence and copresence in Edu-Metaverse can lead to increased learner engagement [37], [38]. However, it should be noted that while the relationship between copresence and learner engagement appears promising, more empirical studies are needed to understand this relationship thoroughly.

C. Metaverse and Edu-Metaverse

The Metaverse exists in a network of interconnected computing devices and includes a range of accessible and decentralized virtual worlds for entertainment, working, and learning. Inside these virtual worlds, people communicate via avatars, which are digital representations of themselves [5]. With distance learning becoming mainstream among educational institutions largely because of the global pandemic, it accelerated the process of developing and deploying virtual worlds for educational purposes, i.e., the Edu-Metaverse [4].

As a new social communication medium with great potential (e.g., connecting the youth and supporting positive interactions [39]), the development of the Metaverse offers a lot of possibilities for education; the enabling technologies can simulate realistic environments and embodied experiences, enhancing the overall learning experience [40]. Vergara et al.[41] suggest that learning in virtual worlds enabled by virtual reality technologies is widely accepted by learners; it is expected that virtual attendance of classes will become more common as the Edu-Metaverse ecosystem evolves.

From the perspective of enabling collaborative learning, the use of avatars in the Edu-Metaverse is unique to other enabling technologies. Avatars are digital representations of learners and instructors in the virtual worlds. Although realistic avatars can enable equally effective socialization and collaboration by rendering facial expressions and body languages [5], not all the collaboration platforms support such realistic avatars as of today. For example, on some platforms (e.g., AltSpace and Virbela[10]), relatively realistic avatars can effectively deliver nonverbal social cues with the assistance of emojis. On other platforms (e.g., Gather), avatars cannot render any nonverbal social cues, although the relative locations of the avatars can still indicate interpersonal activities. Hence, it is important to understand how such differences in the use of avatars supported by these Edu-Metaverse collaboration platforms could potentially affect learning, especially collaborative learning among learners [4], [42].

D. Distance Learning and the 4C Model

Since the outbreak of the COVID-19 global pandemic, online learning or distance learning has become one of the common choices for educational institutions these days. One common approach that has been practiced a lot, especially at the beginning of 2020 when campuses were closed, is creating instant message groups for the class. Using the instant messaging platforms is less formal and is expected to induce more learner–learner and learner–instructor interactions; it is also an effective way for instructors to get more timely feedback and to show their care [43], especially when considering the high prevalence of mental health disorders among learners during the global pandemic [44], [45], [46].

Although the use of instant message groups is useful in inducing a sense of belonging to learning communities and enabling more effective communications, the delivery of the learning content and the collaboration among learners are still important in the distance learning setting. Hence, Chan et al. [12] presented a 4C model, which stands for content, collaboration, community, and communication; the model could be useful for designing online or distance learning. The content component guides the design of how learning content and materials should be delivered to learners. The collaboration component aims to foster active learning through collaborative learning. The community component focuses on how to build learning communities and how to induce a sense of belonging to these communities, even when learners are in distant locations or in a hybrid environment. Finally, the communication components point out that necessary facilities should be provided to enable learner–learner and learner–instructor communication effectively and efficiently. In general, the 4C model can be used for designing hybrid or online learning in general and distance learning in particular. For instance, it can be used to evaluate distance learning tools or platforms in a systematic and outcome-driven way. We shall present and discuss evaluation results based on the 4C model later.

III. Research Question

Based on prior CSCL and the Edu-Metaverse research, we aim to answer three major research questions—the study's primary outcome.

RQ1: Can the Metaverse platforms induce a better sense of copresence during collaborative learning?

RQ2: Will the learners be more engaged in collaborative learning when using the Metaverse platforms?

RQ3: What are the predictive factors of learner engagement during collaborative learning?

RQ1 is a critical area of investigation in the context of CSCL in the Edu-Metaverse era because numerous studies have appraised the potential of multiuser virtual environments and the Metaverse for inducing a better sense of copresence and associated a higher sense of copresence with better learner engagement (e.g., [35], [36], [37], and[38]). *RQ2* is proposed to investigate the claimed advantages of the Metaverse over conventional platforms for CSCL in terms of inducing higher learner engagement. Finally, *RQ3* focuses on finding the predictive factors of learner engagement during collaborative learning. Measuring all possible factors and analyzing their relations with learner engagement is impossible. Hence, based on prior

[10] [Online]. Available: https://www.virbela.com/

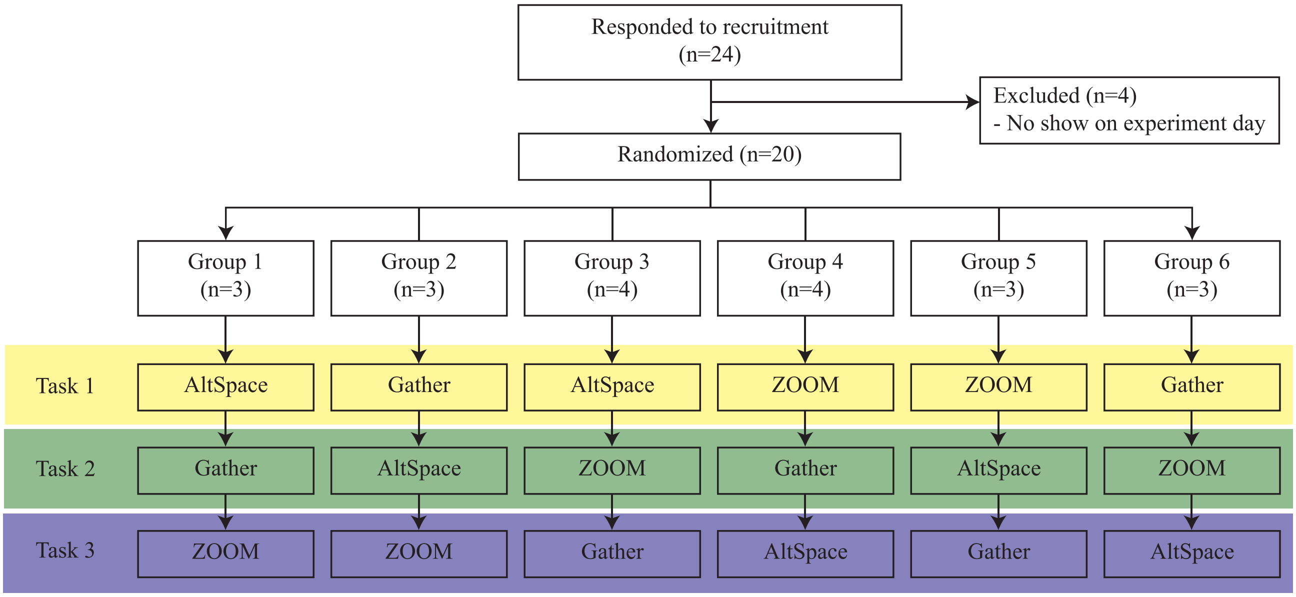


Fig. 1. Flow chart of the study.

research findings, we choose to include system usability and copresence as the two factors to be included in our analyses.

Besides answering these major research questions, the study's secondary outcomes include: 1) identifying existing usability issues of the platforms; 2) understanding learners' preferences in using these platforms for collaborative learning; and 3) studying their conversational patterns and feedback so that potential improvements can be proposed to the enabling technologies, especially the Edu-Metaverse.

IV. Method

A. Experimental Design

This study adopted the within-subject design with three conditions corresponding to three collaboration platforms. Since the concept of the Metaverse and Edu-Metaverse is constantly evolving and new platforms will be continuously released, to make the selected platforms of this study more representative, we chose two Metaverse platforms AltSpace and Gather and included ZOOM to represent conventional video conferencing platforms as the control condition (see Section IV-C). The within-subject design provided maximum control of extraneous participant variables, which is necessary given the relatively small number of participants and potential differences in their academic performance. To mitigate the ordering effects, all participants were randomly assigned to six groups, and each group corresponds to one of the six possible orders of the conditions (i.e., counterbalancing). The details are shown in Fig. 1.

B. Participants

All the participants were recruited via a recruitment announcement made by the Game Design and Development course instructors. In total, 24 students initially responded to the recruitment announcement, of which 20 students (three females and 17 males) participated and completed the study. There were significantly more male students taking this course in the past few years. The gender ratio of our sample generally reflects such gender imbalance. All participants, except three, have previously used virtual reality HMD, mainly for gaming and entertainment. All participants had prior experience in technology-mediated online learning and social networking. The participants were told explicitly that their performance during the study had no impact on the course evaluation. Informed consent was collected from each participant. Research incentives were paid to each participant to compensate for the participation time appropriately. The study was approved by the Institutional Review Board of The Hong Kong Polytechnic University (Reference Number: HSEARS20221021002).

C. Metaverse Platforms and Edu-Metaverse

The three platforms we chose to conduct this study were AltSpace, Gather, and ZOOM, of which AltSpace and Gather are the emerging Metaverse platforms, and ZOOM represents the conventional video conferencing platforms and serves as the control condition in the study.

The differences among these three platforms are detailed in Section I. In summary, AltSpace is selected as an emerging platform that supports the first-person perspective in the virtual worlds and allows the use of the latest enabling technologies (i.e., HMD) to access the virtual worlds. However, the platform may need more collaboration features due to its immaturity. Platforms that can be represented by AltSpace include but are not limited to Mozilla Hubs,[11] VRChat,[12] and RecRoom.[13] Gather is selected to represent platforms that blend the conventional video conferencing with avatar-mediated communications. These platforms

[11] [Online]. Available: https://hubs.mozilla.com
[12] [Online]. Available: https://hello.vrchat.com
[13] [Online]. Available: https://recroom.com

(a)

(b)

Fig. 2. Setting of the experiment room. (a) Setting when using Gather and ZOOM. (b) Setting when a participant was using Oculus Quest 2 HMD to access AltSpace.

may support additional functions that can facilitate collaborative learning better. Similar platforms include but are not limited to ZEP[14] and SpatialChat.[15]

D. Apparatus and Setting

During the study, a 2.5-m-by-2.5-m room was used by each participant in a group of three to four participants. The rooms were designed and built for simultaneous interpretation, and thus, had excellent sound isolation. In each room, we provided the participant with one Oculus Quest 2 HMD and one computer. A webcam was mounted on the top edge of the computer monitor. A pair of headphones was also connected to the computer. The setting is shown in Fig. 2.

The AltSpace virtual reality application was preinstalled in the Oculus Quest 2 HMD and ran as a standalone application during the study. The participants were asked to join a virtual world using the application. The research team designed the virtual world, which reassembled a discussion room (see Fig. 3). The participants used the computer in the room and the desktop version of Gather to join a virtual world on Gather that reassembled a similar discussion room (see Fig. 3). For ZOOM, a meeting ID was created to support the participants' discussion.

(a)

(b)

Fig. 3. Virtual discussion rooms created for this study. (a) Virtual discussion room in AltSpace. (b) Virtual discussion room in Gather.

E. Procedure

Successfully registered participants were first asked to sign the consent forms and were given the three course-specific discussion topics one week before completing the collaborative learning tasks in our laboratory. The topics were one-button game design, puzzle games with combos, and games about Chinese culture. The discussion topics were provided in written form and supplemented with three short videos by the course instructor two weeks before the laboratory experiment. Each participant was randomly assigned to one of the six discussion groups. Each group had three to four participants. The participants were told to research the topics in advance, bring their findings for discussion, and complete the collaborative learning tasks in our laboratory during the assigned time slot.

On the day of the laboratory experiment, each participant of the same group was assigned to his/her own room (see Section IV-D), and the group would use three platforms in a predefined sequence to complete three collaborative learning tasks corresponding to the three course-specific discussion topics. The use of each platform was limited to 20 min, of which a maximum of 15 min were to prepare for completing the task collaboratively, and 5 min were to let the group present their collaborative learning outcomes in the form of pitching a game design idea. The procedure was similar to how the Game Design and Development course students normally complete

[14][Online]. Available: https://zep.us/
[15][Online]. Available: https://www.spatial.chat/

TABLE I
RELATIONS BETWEEN THE COLLECTED DATA AND THE INTENDED OUTCOMES OF THIS STUDY

Data	Primary outcomes			Secondary outcomes
	RQ1	RQ2	RQ3	
NMMSP	✓		✓	
DES		✓	✓	
SUS			✓	✓
Preference				✓
Conversation				✓
Interview				✓

collaborative learning tasks in class. After using each platform, the participants were asked to complete the questionnaires. The authors conducted a semistructured interview with the group after they had completed all three collaborative learning tasks using the three platforms (see Section IV-F6). The entire procedure is illustrated in Fig. 1.

F. Data Collection

Quantitative data, including the measures of copresence, learner engagement, and system usability, were collected to answer the three major research questions. Meanwhile, the participants' preferences toward the three platforms for collaborative learning, their conversational data, and qualitative feedback extracted from the semistructured interviews were used to achieve the secondary outcomes. The relations between the data collected and the study's outcomes are shown in Table I, and the details are as follows.

1) Copresence: The copresence subscale of the networked minds measure of social presence (NMMSP) [47] was used to measure the participants' perceived sense of copresence when using the three platforms to complete the collaborative learning tasks. The subscale has 14 items on a seven-point Likert-type scale ranging from "strongly disagree" (1) to "strongly agree" (7).

2) Learner Engagement: The discussion engagement scale (DES) [48] was used to measure the participants' engagement when using the three platforms to complete the collaborative learning tasks. It has 22 items on a five-point Likert-type scale. The 22 items belong to four dimensions, namely discussion skills, confidence, inclusive climate, and openness. Items under each dimension have specific response anchors.

3) Usability: The system usability scale (SUS) [49] was used to measure the usability of the three platforms. The scale is one of the most widely used instruments to conduct subjective assessments of usability. It has ten items on a five-point Likert-type scale ranging from "strongly disagree" (1) to "strongly agree" (5).

4) Platform Preference: To understand the participants' preferences toward the three platforms, we asked every participant to give each platform a one-to-five score under each of the four dimensions, namely content, collaboration, community, and communication, under the 4C model [12]. The participants were also asked to give their reasons for the scoring.

5) Conversational Activities: Participants' performance in each platform was also evaluated by analyzing their interactions, which provided important information regarding how comfortable participants felt within a medium [50]. In this study, we focused on analyzing the average conversational frequency of each group in the group discussion part through each platform. The average conversational frequency is computed by the total number of conversational turns over the total discussion length. Annotations and analyses were made based on the audio and video recordings. To improve the accuracy of the analysis, all interactions were first counted by two authors (Y. Jiang and F. Cheung) independently, and then, further checked by a third author (C. Li) if there was any discrepancy. In the end, all three authors agreed on the data for further analysis.

6) Semistructured Interview: To achieve the secondary outcomes of the study, after completing all three collaborative learning tasks using the three platforms, the author (C. Li) conducted a semistructured interview with each group of participants. The semistructured interview consisted of two halves. The first half focused on the participants' preferred platforms in the context of using them for collaborative learning. The second half focused on the potential improvements to each platform under the same context. The semistructured interviews were audio recorded.

G. Quantitative Data Analysis

Descriptive statistics were calculated and reported for each condition (i.e., each of the three platforms). The two-way analysis of variance (ANOVA) was conducted to examine the effects of groups and conditions on the participants' sense of copresence, discussion engagement, and perceived system usability. If there were significant effects, postdoc pairwise comparisons would be conducted with Bonferroni adjustment. Linear regression with the copresence and SUS scores as independent variables and the DES scores as the dependent variable was conducted to examine the predictive factors of learners' engagement during collaborative learning. The data analyses were performed using IBM SPSS Statistics[16] Version 26. A significance level of 0.05 was used across all analyses.

H. Qualitative Data Analysis

Thematic analysis was employed for analyzing the qualitative data we collected through the semistructured interviews [51]. The audio recordings were first transcribed and verified, followed by coding. The coding process focused on identifying and highlighting segments of the data that were relevant to the following:

1) the participants' impressions and feelings toward the three platforms and the corresponding enabling technologies;
2) their impressions and feelings toward the virtual presence of their classmates;
3) the comparisons of functionality across the platforms;
4) the potential improvements to the platforms.

The identified patterns and themes were refined, and compelling extract examples were selected for final analysis and reporting.

[16][Online]. Available: https://www.ibm.com/products/spss-statistics

TABLE II
DESCRIPTIVE STATISTICS OF THE MEASURES GROUPED BY THE THREE COLLABORATION PLATFORMS

	Copresence	SUS	DES				
			Skills	Confidence	Inclusive climate	Openness	Combined
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
AltSpace (*n*=20)	5.51 (0.670)	52.25 (24.440)	2.97 (0.613)	3.97 (0.531)	4.05 (0.673)	3.65 (0.498)	3.69 (0.234)
Gather (*n*=20)	4.95 (1.084)	66.25 (15.655)	3.17 (0.617)	3.71 (0.548)	3.68 (0.751)	3.58 (0.458)	3.55 (0.392)
ZOOM (*n*=20)	4.65 (0.914)	75.75 (10.422)	3.06 (0.503)	3.53 (0.467)	3.43 (0.643)	3.62 (0.467)	3.42 (0.283)

TABLE III
PAIRWISE COMPARISONS WITH BONFERRONI ADJUSTMENT OF CONDITIONS (I.E., COLLABORATION PLATFORMS) ON COPRESENCE SCORES

Pair	Mean Diff. (SE)	p	95% CI
AltSpace-Gather	0.561 (0.286)	0.165	[-0.146, 1.267]
AltSpace-ZOOM	0.857 (0.286)	0.012	[0.151, 1.564]
Gather-ZOOM	0.296 (0.286)	0.915	[-0.410, 1.003]

TABLE IV
PAIRWISE COMPARISONS WITH BONFERRONI ADJUSTMENT OF CONDITIONS (I.E., COLLABORATION PLATFORMS) ON DES SCORES

Pair	Mean Diff. (SE)	*p*	95% CI
AltSpace-Gather	0.141 (0.098)	0.469	[-0.101, 0.383]
AltSpace-ZOOM	0.273 (0.098)	0.022	[0.031, 0.515]
Gather-ZOOM	0.132 (0.098)	0.553	[-0.110, 0.374]

V. RESULT

A. Platforms on Copresence

The descriptive statistics of the participants' perceived copresence as measured by the NMMSP copresence subscale and grouped by three collaboration platforms are shown in Table II. A two-way ANOVA was conducted to examine the effect of groups and conditions on the participants' perceived sense of copresence. No statistically significant interaction between the effects of groups and conditions on copresence was found, $F(10, 42) = 0.920, p = 0.525$. The effects of groups on copresence were not statistically significant either, $F(5, 42) = 0.908, p = 0.485$. However, the effects of conditions on copresence were statistically significant, $F(2, 42) = 4.457, p = 0.018$. The results of the pairwise comparisons with Bonferroni adjustment of conditions on copresence are shown in Table III.

B. Platforms on Learner Engagement

The descriptive statistics of the participants' engagement during discussions as measured by DES and grouped by three collaboration platforms are shown in Table II. A two-way ANOVA was conducted to examine the effect of groups and conditions on DES scores. No statistically significant interaction between the effects of groups and conditions on DES scores was found, $F(10, 42) = 0.428, p = 0.925$. The effects of groups on DES scores were not statistically significant either, $F(5, 42) = 1.948, p = 0.107$. However, the effects of conditions on DES scores were statistically significant, $F(2, 42) = 3.783, p = 0.031$. Regarding the four subscales of DES, we found that there were statistically significant effects of conditions on confidence, $F(2, 42) = 3.643, p = 0.035$, and inclusive climate, $F(2, 42) = 3.635, p = 0.035$. The results of the pairwise comparisons with Bonferroni adjustment of conditions on DES scores are shown in Table IV.

C. Platforms on Usability

The descriptive statistics of the subjective measures of the system usability are shown in Table II. A two-way ANOVA was conducted to examine the effect of groups and conditions on SUS scores. There was a statistically significant interaction between the effects of groups and conditions on SUS scores, $F(10, 42) = 2.304, p = 0.029$. The effects of groups on SUS scores were statistically significant, $F(5, 42) = 4.558, p = 0.002$. The effects of conditions on SUS scores were also statistically significant, $F(2, 42) = 14.774, p < 0.001$. The results of the pairwise comparisons with Bonferroni adjustment of conditions on SUS scores are shown in Table V.

TABLE V
PAIRWISE COMPARISONS WITH BONFERRONI ADJUSTMENT OF CONDITIONS (I.E., COLLABORATION PLATFORMS) ON SUS SCORES

Pair	Mean diff. (SE)	*p*	95% CI
AltSpace-Gather	-14.000 (5.630)	0.048	[-27.888, -0.112]
AltSpace-ZOOM	-23.500 (5.630)	<0.001	[-37.388, -9.612]
Gather-ZOOM	-9.500 (5.630)	0.291	[-23.388, 4.388]

TABLE VI
DESCRIPTIVE STATISTICS OF THE PARTICIPANTS SCORING OF THE PLATFORMS BASED ON THE 4C MODEL

	Content	Community	Communication	Collaboration
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
AltSpace	2.95 (1.099)	4.25 (0.786)	3.75 (0.967)	3.40 (0.940)
Gather	4.00 (0.725)	4.05 (0.826)	4.05 (0.826)	4.10 (0.788)
ZOOM	3.95 (0.759)	3.30 (1.174)	3.70 (1.218)	3.80 (0.894)

D. Predictors of Learner Engagement

A simple linear regression was calculated to predict learner engagement during collaborative learning based on the platforms' usability and the sense of copresence experienced by all participants across three platforms. A significant regression equation was found, $F(2, 57) = 3.877, p = 0.026$, with an R^2 of 0.364. The standardized regression coefficient (β) of the copresence scores was 0.322 ($p = 0.013$); the standardized regression coefficient (β) of the SUS scores was -0.081 ($p = 0.521$).

E. Platform Preference

Detailed scores of the three collaboration platforms based on the 4C model [12] are summarized in Table VI and visualized in Fig. 4.

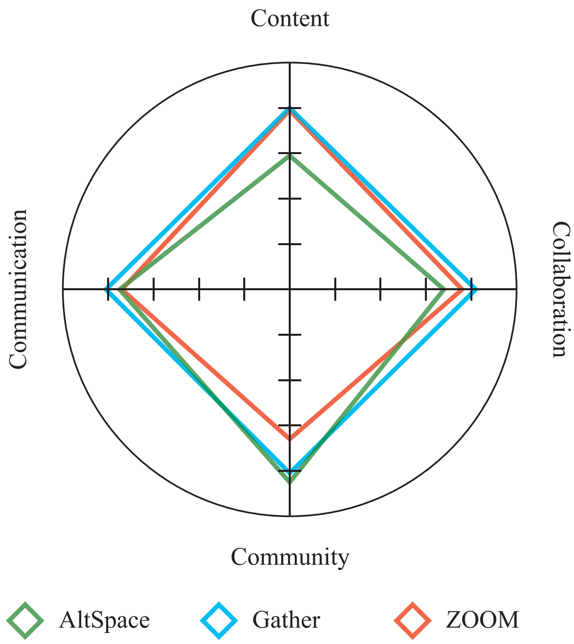


Fig. 4. Participants' scoring of the platforms based on the 4C model [12].

TABLE VII
STATISTICS OF THE CONVERSATIONAL ACTIVITIES OF THE PARTICIPANTS ACROSS THREE COLLABORATION PLATFORMS

	Length (second)	Total turns	Averaged turns
AltSpace (*n*=16)	2038	304	8.95
Gather (*n*=16)	2693	330	7.35
ZOOM (*n*=20)	3278	394	7.21

F. Conversational Activities

The statistics of the participants' conversational activities, including the total length of conversations, total number of conversational turns, and averaged conversational turns per 60 s (i.e., conversational frequency), are presented in Table VII across the use of three collaboration platforms. Only conversations relevant to the collaborative learning tasks are counted here. Four participants' conversational activities in AltSpace and Gather were not analyzed due to data corruption.

G. Qualitative Results

The thematic analysis helped us identify 55 segments of the qualitative data relevant to the participants' impressions and feelings toward the three platforms and the corresponding enabling technologies, 31 segments relevant to their impressions and feelings toward the virtual presence of their classmates, 73 segments related to the comparisons of the functionality across the three platforms employed for this study, and 45 segments in which the participants proposed potential improvements to the platforms. Some feedback is presented in Section VI to facilitate the discussion.

VI. Discussion

A. Platforms on Copresence

Regarding whether the Metaverse platforms induced a better sense of copresence during collaborative learning (*RQ1*), our results suggest that the participants experienced a significantly higher sense of copresence in AltSpace, compared to ZOOM, which is not unexpected. Meanwhile, the results also suggest that the participants did not experience a significantly higher sense of copresence in Gather compared to ZOOM. The results generally match with prior studies from both the virtual reality and educational technology research communities, which suggest that the presence and copresence are highly correlated [36], [52], [53]; the levels of realism and immersion that are enabled by Gather on conventional computer monitors are much lower than AltSpace in HMDs. Apparently, AltSpace also brought a stronger sense of learning community to the participants according to their scoring of the platforms based on the 4C model [12]. Although AltSpace was behind the other two platforms on the content and collaboration dimensions due to its immaturity (see Section VI-D), its advantage in bringing a sense of learning community is very valuable. As suggested by prior studies, a strong learning community cultivates a sense of belonging among its members, which can boost motivation, engagement, and satisfaction in learning significantly [54], [55]. During the semistructured interviews, many participants used words such as "cosy," "close," and "relaxed" to describe their feelings and the virtual discussion room in AltSpace. One participant in Group 4 said he felt being "closer to and more connected with other classmates" in AltSpace. As the Edu-Metaverse ecosystem grows rapidly [4], we believe many issues of the fully immersive platforms for collaborative learning and avatar-mediated communication (e.g., AltSpace) will soon be ironed out and using such platforms can better connect learners in the distance learning setting via enhancing the sense of copresence.

B. Platforms on Learner Engagement

Regarding whether the learners will be more engaged in collaborative learning when using the Metaverse platforms (*RQ2*), the participants seemed to be more engaged in the group discussion when using AltSpace and Gather, as shown in our data analyses. A further look into the subscales of the DES also suggested that the participants had high discussion confidence and experienced a better inclusive climate when using AltSpace. The qualitative feedback from the participants suggests similar findings. For example, one participant from Group 3 mentioned that he felt that "time went faster when using AltSpace" than using Gather or ZOOM because he believed "the other classmates were more engaged in the discussion [when using AltSpace]." One participant from Group 2 also said that "the lack of certain functions [in AltSpace] actually helped to be more concentrated on the [collaborative learning] task." At least three participants mentioned that using ZOOM was considered "very formal" since they always associated ZOOM with teaching rather than collaborative learning tasks. Compared to ZOOM, one of the three participants who were in Group 6 said that AltSpace and

Gather were felt to be more "playful" than ZOOM and other conventional video conferencing platforms. One participant in Group 2 said that she "did not need to care about what is happening around [her in AltSpace]," which could help her focus on completing the collaborative learning tasks. Meanwhile, we should admit that there might be some novelty effects of using a new collaboration platform through HMDs. Previous reviews mention the novelty effects of using virtual and augmented reality technologies for educational purposes (e.g., [56], [57], and [58]). The participants used words, such as "new," "interesting," "unseen," and "attractive" to describe AltSpace and the use of HMDs, which may indicate the potential novelty effects. However, empirically and systematically investigating this question requires conducting longitudinal studies, which goes beyond the scope of this study.

C. Copresence Predicting Learner Engagement

The sense of copresence experienced by the participants is found to be a strong predictor of their engagement during collaborative learning, but the system usability of the platforms is a very weak predictor (*RQ3*). We thought the system usability could be a strong predictor of the participants' engagement during collaborative learning because a collaboration platform with poor usability could easily distract its users, resulting in lower user engagement and performance, as reported in prior studies (e.g., [59] and [60]). On the other hand, Dahleez et al. [60] suggested that the link between the e-learning system usability and emotional engagement in their study was not significant; this is one potential explanation to the result since the instrument we used for measuring engagement (i.e., the DES; see Section IV-F2) covered emotional engagement to a great extent [48].

Meanwhile, we should note that the linear regression model could only explain 34.6% of the variance in the dependent variable (i.e., learners' engagement as measured by the DES). Although other potential factors, such as the presence of instructors [61], feedback to learners [62], and learners' self-regulation and self-esteem [38], might contribute to learners' engagement and explain the variance in the dependent variable in the distance learning setting, we could not find empirical studies that investigate this research problem in the context of using Metaverse platforms for collaborative learning tasks. We encourage future studies to explore other factors potentially contributing to learners' engagement in this context.

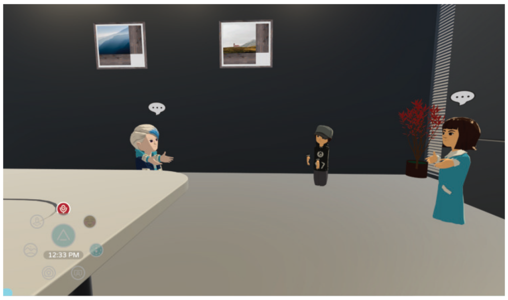
D. Usability Issues

The quantitative results suggested that AltSpace had severe usability issues, especially compared to the other two platforms. The qualitative evidence further revealed the underlying issues; many participants said the HMDs felt "heavy," "bulky," and "loose." The negative feelings toward HMDs affected the participants' perceived ease of use toward AltSpace.

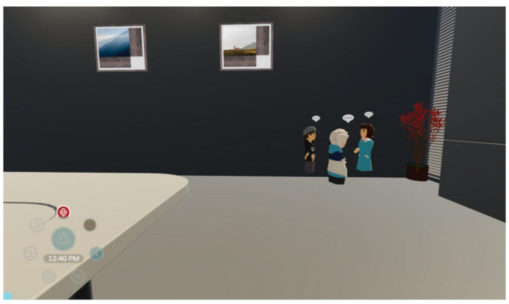
Specifically, the HMD used by one participant in Group 3 always went to sleep mode. The HMD's proximity sensor was somehow faulty. The participant said that was his "first time using a VR device"; he was "excited at the beginning," but the faulty sensor made him feel "very frustrated." The prescription glasses of one participant in Group 4 were too large to be worn while using the HMD. The texts were "quite blurry and hard to read" to him, and he believed the blurry texts caused his headache after using the HMD. A common issue reported by many of the participants was the foggy lenses of the HMDs. As the pandemic controlling rules were still in place in Hong Kong when the study was conducted, the participants had to wear masks during the laboratory experiment. Thus, their breaths could easily cause fog on the HMDs' lenses.

With the usability issues of the HMDs noted, we further asked the participants about their thoughts toward the user interface of AltSpace. Surprisingly, almost all participants gave more positive feedback. The participants generally like the user interface. Meanwhile, several participants in Groups 2, 5, and 6 mentioned wanting to have other participants' names shown in AltSpace. That would make "knowing each other much easier" because the visual appearance of their avatars was "far from the real [appearance]" in virtual reality. To follow this topic on avatars, we further asked whether they preferred avatars closer to their actual appearance in the physical world. All participants from the three groups rejected the idea except for one participant from Group 2, who said that "it depends on the nature of the meeting." One participant from Group 1, who had much experience in developing virtual reality applications, said that he liked the idea of having "talking bubbles above other people's heads when they talk" because, to him, this was an obvious indication of who was talking. He also liked the change of gaze directions as his avatar approached other avatars because it made him think "other people were paying attention" to him.

Meanwhile, although the qualitative results suggested that the usability of Gather was less of a concern, the qualitative feedback of the participants suggested that they also encountered two major usability issues. The first major issue is related to the user interface design. For example, during the semistructured interview, several participants mentioned needing better clarification on whether their webcams had been turned ON. This is because Gather placed the webcam feed to the bottom right corner of the screen, and the video size is small. Such issues can be solved as the platform becomes more mature. The second major issue is the design of the discussion room. The discussion room we designed (see Fig. 3) in Gather was too large for the collaborative learning tasks involving three to four learners. During the semistructured interview, the participants in Groups 5 and 6 mentioned that they had to move their avatars in a group between the whiteboard and the desks. The whiteboard was where they discussed, but the desks were where the tasks were presented as embedded documents. Although they liked reading documents in the virtual discussion room, if some group mates left to view the documents, they could not hear what others were discussing. This is how Gather simulates the effects of interpersonal distance; once the distance between two avatars exceeds a threshold, they suddenly cannot see or hear each other. With this in mind, we should make the room smaller for three to four people and place more "spotlight" tiles, which could make the avatar standing on top be heard by all others in the room.



(a)



(b)

Fig. 5. Example showing that participants were getting closer in AltSpace as the collaborative learning progressed and there was more cross talking as indicated by multiple "talking bubbles" at the same time. (a) Participants' avatars at the beginning of the discussion. (b) Participants' avatars near the end of the discussion.

E. Other Observations and Implications

There are three other observations we found during the study. First, although the quantitative data suggested that the participants were more engaged in the collaborative learning tasks when using AltSpace and Gather, the course instructors did not see any effects of collaboration platforms on task performance. The quality of their discussion and the collaborative learning outcomes largely depended on how well-prepared they were before joining the experiment. Second, we found that the participants in a group tended to get closer in AltSpace as the collaborative learning progressed (see Fig. 5). The distances between their avatars (i.e., the interpersonal distances in the virtual world) generally matched with the observed social distance for interactions among acquaintances [63], [64]. Finally, we found that the patterns of organizing the collaboration were different when using different platforms. The participants were told that each group needed to have one member present their group's game design ideas by the end of the discussion. Hence, they tended to select one member first and let him or her lead the discussion using ZOOM. However, in AltSpace or Gather, this tendency was not very obvious. Especially in AltSpace, instead of having someone present his or her ideas and findings first, all groups started in a less formal conversation climate. Also, there were significantly more conversational turns per 60 s as shown in Table VII. This phenomenon is interesting and has not been studied thoroughly before in the context of collaborative learning in the distance learning setting.

VII. Limitation

First, the gender imbalance of the participants and course-specific collaboration tasks may limit the generalizability of the results and findings. Prior studies have suggested that gender diversity might affect social behaviors during and outcomes of collaborative learning [65], [66]. Although the gender ratio of the participants of this study generally matches the gender ratio of the students taking the Game Design and Development course, we still want to know whether the results and findings also apply to female learners. It would also be interesting to further investigate the effects of gender diversity on collaborative learning in the Edu-Metaverse through future studies, given the fact that gender diversity in the Metaverse is an important but largely unexplored area [67].

Second, the collaborative learning tasks on proposing game design ideas are specific; they mainly require the learners to exchange design ideas, imagine, brainstorm, and propose a playful solution, which does not involve hands-on practice. However, in many other computer science courses, collaborative hands-on practicing is a common way to help learners achieve the corresponding learning outcomes. We plan to investigate this problem in future studies.

The third limitation is that the comparison between emerging Metaverse platforms (i.e., AltSpace and Gather) and a mature video conferencing platform (i.e., ZOOM) might be biased. The immaturity of the Metaverse platforms can be seen in the lack of particular functions for collaboration and less-than-ideal user interfaces. For example, as mentioned by many participants during the semistructured interview, AltSpace lacks the shared whiteboard function; some of the user interface elements of Gather need to be clarified. In addition, the ergonomics of the HMDs used to access the discussion room in AltSpace is also a prominent issue, given the current generation of entry-level off-the-shelf HMDs. Meanwhile, considering the immaturity of AltSpace and Gather, it is inspiring to see such the Metaverse platforms have great potential to bring a better sense of learning community and inducing higher levels of engagement among learners in the distance learning setting.

Finally, the laboratory experiment is one-time. However, in reality, group discussions and other collaborative learning tasks can happen multiple times (e.g., during an entire semester spanning four months). Hence, we plan to conduct longitudinal studies to investigate the effects of the long-term use of the Metaverse platforms for collaborative learning. The planned longitudinal studies will also help us better investigate the novelty effects.

VIII. Conclusion

Motivated by the fast adoption of Metaverse platforms for educational purposes and the emerging concept of the Edu-Metaverse, we conducted an empirical study focusing on investigating how Metaverse technologies can support collaborative knowledge construction in the distance learning setting. To simulate the process of completing collaborative learning tasks remotely, 20 undergraduate students (three females and 17 males) taking the Game Design and Development course were invited to use three carefully selected platforms in our laboratory for discussing three course-specific topics: one-button game design, puzzle games with combos, and games about Chinese culture. The quantitative results suggest that despite some usability issues, the participants were more engaged in the collaborative learning tasks when using Metaverse platforms that offer avatar-mediated communications with clear indications of interpersonal activities (i.e., AltSpace and Gather); AltSpace also gave the participants a stronger sense of copresence and belonging to the learning community. It was also found that the participants' sense of copresence was correlated with their engagement. Moreover, the qualitative feedback from the participants helped us identify the learners' needs and issues with the relatively immature platforms. With the knowledge and know-how gained through this study, we plan to expand the scope of the study and address the limitations (see Section VII) in the near future.

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