Virtual Classmates: Embodying Historical Learners' Messages as Learning Companions in a VR Classroom through Comment Mapping

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Abstract

Online learning platforms such as MOOCs have been prevalent sources of self-paced learning to people nowadays. However, the lack of peer accompaniment and social interaction may increase learners' sense of isolation and loneliness. Prior studies have shown the positive effects on visualizing peer students' appearances with virtual avatars or virtualized online learners in VR learning environments. In this work, we propose to build virtual classmates, which were constructed by synthesizing previous learners' messages (time-anchored comments). Configurations of virtual classmates, such as the number of classmates participating in a VR class and the behavioral features of the classmates, can also be adjusted. To build the characteristics of virtual classmates, we propose a technique called comment mapping to aggregate prior online learners' comments to shape virtual classmates' behaviors. We conduct a study with 100 participants to evaluate the effects of the virtual classmates built with and without the comment mapping and the amount of virtual classmates rendered in VR. The findings of our study suggest design implications for developing virtual classmates in VR environments.

1 Introduction

With the rapid development of online learning platforms, more and more people start their self-paced learning by taking online courses. However, compared with traditional classrooms, online learners lose the social connection with others, which has been seen critical to enhance learners' interests, motivation and persistence on learning tasks [40]. Online learners often fail to keep their motivation and cannot complete their learning goals due to the feeling of isolation [9]. To solve this problem, many studies tried to offer more channels for online learners to interact with others such as discussion forums and chatrooms [8, 25]. Nevertheless, these do not solve the problem effectively due to the low participation of learners in these communication channels [21].

To improve learners' participation and interaction, Chen [5] and Kostarikas et al. [24] simulated virtual classrooms on the Second Life platform and transformed online users into virtualized instructors and students, where a "virtualized instructor/student" refers to the avatar of a real instructor/student, who indeed controls the behavior of the avatar online. On the other hand, a "virtual student" refers to an avatar whose behavior is controlled by a computer. Inside the virtual world, online learners have a feeling of their presence and can collaborate and interact with other virtualized learners immersively.

To further enhance learners' immersion and build more realistic interactions, several researchers simulated learning scenarios and utilized avatars in VR environments [6, 34]. VR takes learners into the contexts and strengthens learners' feeling of seeing others and being there. While the presence of virtualized classmates successfully increases online learners' motivations and social interactions, this mechanism requires all online learners and the instructor taking the same course to be online at the same time, which conflicts the goal of self-paced learning. Besides, in a virtual world, the number of avatars available for learners to interact with is limited. In fact, overfull virtualized classmates might cause negative impacts on learners' learning experiences because of the disturbances and distractions introduced by a big group.

In this paper, we propose the notion of virtual classmates, which are not puppets controlled by online learners but virtual characters simulated based on previous learners' time-anchored comments [27]. Time-anchored comments are notes generated by real students that are attached (anchored) to specific time points of a video, so that future video learners will be able to reread these comments when playing-back the video. Through time-anchored comments that would be shown with dialog boxes according to the playing time of the video, virtual classmates allow individual learners to take the same class asynchronously but the learners can still have a feeling of learning with others. Moreover, since virtual classmates are regenerated based on real learners' verbal responses, there exists flexible ways to manipulate their generation. For example, the amount of virtual classmates can be configured freely. The mapping between real learners and virtual students can also be diversified. Multiple learners with similar verbal responses can be mapped to the same virtual classmate. Or the characteristics of virtual classmates can be controlled by filtering out undesired comments. Since the creators are able to manipulate the way of constructing virtual classmates, virtual classmates with functionalities can become peer models for online learners whom the learners could observe and follow with to enhance comprehension and motivation of learning [33]. Virtual classmates could help learners feel the sense of accompany and influence their learning behaviors.

To realize the idea of virtual classmates, we propose a comment mapping method that utilizes real learners' time-anchored comments [27] to create virtual classmates. The comment mapping method first clusters online learners' comments based on the similarity of their content and types. After clustering, the comments from the same cluster would be mapped to one or multiple virtual classmates, while comments from different clusters would not be mapped to the same virtual classmate. Hence, the generated virtual classmates would exhibit behaviors of particular styles like questioners, complainers, or active scholars. Besides, we also analyze the emotion of each time-anchored comment and add the emotional reaction to a virtual classmate when s/he acts the comment.

We further develop a VR classroom in which online learners can watch a video lecture with virtual classmates. Then we conduct a between-subject experiment in a lab setting using our system to evaluate the influences of VR learning environments and virtual classmates with two factors, comment mapping and the number of virtual classmates. Our findings show that comment mapping is helpful for learners' learning outcomes in the condition with fewer virtual classmates (five), while comment mapping may decrease learners' social interactivity in the same condition. From the interviews, we discover that overall VR could help learners concentrate

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on the course and immerse them into the virtual learning environment.

This research intends to make three contributions: (1) Building a prototype VR classroom integrated with virtual classmates by mapping real learners' time-anchored comments to them; (2) Proposing a new technique, comment mapping, to map multiple real learners' messages to comments presented by a limited number of virtual classmates and studying its effects on online learners. (3) Investigating the influences of key design factors - whether and how comment mapping, the number of virtual classmates, and VR environment - on learners' learning outcomes, social interactivity, and focused attention.

2 Related Work

We review related work on learning in the virtual world and previous studies on using peer communication to improve isolation and lack of interaction in online learning. We also surveyed studies on employing agent-based virtual classmates as learning companions for learners who were learning online.

2.1 Learning in Virtual Environments

Non-VR platforms. Second Life (SL) is an online virtual world that allows highly realistic enactment of real life activities online. SL offers instructors an easy way to teach and interact with learners in a virtual environment. Kostarika, s et al. [24] integrated distance-learning platforms into SL. Learners could learn in classrooms or laboratories, have quizzes, and interact with classmates. Some studies [1, 41] used SL to create virtual labs to let learners complete possibly dangerous experiments in a safe environment. Chen [5] designed a full-blown task-based syllabus that capitalized on meaningful real-life tasks in SL, learning English by completing the tasks. In addition to SL, there were other researchers [18, 22, 29] created games to let learners learn knowledge and collaborate with others in the virtual environments while playing.

VR platforms. Apart from just using desktop computers to access the virtual environments, dedicated VR devices such as head-mounted displays brings people into the environments more realistically. Some studies [14, 28, 38, 44] used VR in situated learning to immerse the students into the related situations. Game for Learning [2, 16, 32] was also a way to use VR. They designed games to make learning more interesting. Other previous studies [6, 34, 46] created multi-user environments to let students learn and communicate synchronously online. In the current work, we explored adding virtual classmates to improve the realism of a VR classroom, and immerse the learners into the learning environment by simulating their prior experience of learning with classmates in physical classrooms. One enabling feature is that learners in our VR classroom don't need to be online at the same time to receive the benefits of social interaction, since the system can supply learners with time-anchored comments [27] and emotional reactions [39] by using virtual classmates to provide social co-presence (i.e., the feeling of being there together online) [3], which make learners feel that they're sharing the time and space with their learning companions.

2.2 Communication in Online Learning

Most online courses have their own discussion forums for learners to ask questions or make in-depth discussions around specific topics. Ezen-Can et al. [11] grouped the similar posts and hoped to help learners quickly find the information they need. Sunar et al. [35] analyzed the posts in discussion forums to investigate the learners' social behaviours and the impact of engagement on course completion. Although discussion forums let learners leave comments to interact with others, no instant response may lead to less engagement of learners.

Hence, some researchers [8, 25] grouped learners to enable synchronous online discussions, and found that talking to others triggered learners' innovations and motivation to learn. Hamilton et al. [17] used live streaming to let instructors and learners interact synchronously. Instructors could use live streaming audio, webcam videos, and screenshares for teaching. When instructors asked a question, learners could give feedback by texts, images, etc. However, it may be a problem to require learners taking courses online at the same time since one of the great features of online learning is that learners can learn whenever and wherever they are free. In addition to synchronous communication, Dorn et al. [10] proposed a system to let learners leave comments while watching the lecture videos like the time-anchored system. Learners could leave a comment at a specific time point of the video and then mark on the video for that comment.

Our VR classroom uses virtual classmates to present the time-anchored comments. Although time-anchored comments were not synchronous discussion like those in [8, 25], they could make learners feel that there are real classmates synchronously speaking out their thoughts while learning in the VR classroom. We are able to transform these responses as prompts for future learners to think and learn, going beyond the limitations imposed either by the designs of online forums or time-anchored systems [10, 27].

2.3 Learning Online with Virtual Colearners

Chatzara et al. [4] used agents who were able to portray emotions to support learners in traditional e-learning environments. The agents gave the learners the clues for their tasks with emotional behaviors including facial expressions, hand gestures and body movements. Besides emotions, there were other studies that attempted adding personality to agents. Yamada et al. [42] proposed an application of socially intelligent agents for enhancing e-learning. In their system, a learner would see a virtual instructor and a virtual classmate. When the virtual instructor gives questions to the learner, the virtual classmate would show different responses based on his/her personalities and whether the learner's answer was correct. Gebhard [13] proposed a model to let designers set virtual characters' personalities and applied it to a virtual learning environment. The virtual characters would change their moods and emotions because of some events, objects and actions, then give corresponding reactions to the users. Fatahi and Ghasem-Aghaee [12] developed a virtual environment with a virtual tutor agent and a virtual classmate agent to assist learners' learning. A learner would fill in a questionnaire first and the system would choose a teaching style and agents for the learner based on his/her personality acquired from the questionnaire. Through the learner's learning behaviors, the system would analyze his/her current emotion and let the agents give corresponding pre-designed responses according to the agents' personalities and the learner's emotion. All of these studies used pre-designed dialogues to respond to the learners based on their feedback.

To create a virtual classroom, we considered that there would not be just one classmate like [42] in our classroom. Instead of pre-designed dialogues [4, 12, 13], we used time-anchored comments which were left by real classmates to make the virtual classmates behave more like real ones in the same course. Although we did not use agents, we think intelligent agents or chatbots can be included in our system to complement our virtual classmates in the future. In this study, we focused on increasing the realism and varieties of verbal feedback captured in real online learning settings. Like previous studies [12, 13, 42], we want to let the virtual classmates possess their own personalities. From the time-anchored comments [27] we used, we find that real learners have a variety of ways to express their feelings which are very relevant to learning such as asking questions or taking notes. We consider the ways of adopting real learners' expressions a suitable factor to design our virtual classmates.

3 METHOD AND SYSTEM

We develop our system on Unity by adopting a classroom model as the VR classroom and making 3D character models as the virtual classmates with MakeHuman[1]. We apply the time-anchored comments collected from time-anchored commenting system [27] as online learners' feedback data. In the scene (Figure 2), users would see the course video in front of the classroom and the virtual classmates sitting in the classroom with the dialogue boxes showing up time-anchored comments along with the playing of the video. Our system allows the users to select their preferred seat before and during the class to make realistic experience in the VR classroom. This also avoids the discomforts due to inappropriate viewing distances or angles to the video. To make virtual classmates behave more realistically, we develop two techniques, comment mapping and motion mapping.

3.1 Comment Mapping

In the process of building virtual classmates, the method of distributing real learners' feedback comments into few virtual classmates can influence learners' sensation and recognition of virtual classmates. Randomly mapping real learners' comments to virtual classmates may cause inconsistent characteristics of virtual classmates. The personality, mood, or behavior of a virtual classmate may change abruptly, which makes the virtual classmate look unrealistic. Comment mapping may also impact learners' strategies to learn from virtual classmates' comments. For example, with random mapping, learners would feel every classmate as the same and need to put their efforts to seek out preferred information. However, if we manipulate the mapping of comments to make the functionality and characteristics of virtual classmates more salient and unique, learners may feel their classmates being more realistic and referable for learning.

We develop comment mapping techniques to make characterized virtual classmates. When taking courses online, learners might show their habits, emotions or preferences. Some learners might take notes of the course content more often, or some others may prefer raising questions in the class. Hence, we can group and map the comments of similar learners to the same virtual classmate to let users feel that they are taking courses with real classmates. To calculate the similarities of real online learners, we apply the content analysis proposed by Sung et al. [36], which classified comments based on their interactive or self-expression features into seven categories: general conversation, notes, opinion, question, complaint, compliment, and others.

For completeness, we briefly describe the content analysis method [36]. In the preprocessing stage, each comment is split into words using a Chinese text-segmentation module, *Jieba* (http://github.com/fxsjy/jieba). Stop-word filtering is applied and a part-of-speech (POS) tag for each word is produced. Each comment then contains only meaningful words.

Naïve Bayes classifier is used to classify the content type of comments as it performs well when training data is limited. Each type of analysis is formulated as a two-class classification problem, i.e., target type vs. non-target type. For example, if *notes* is the target type, then all comments that are not notes are treated as the non-target type. Six classifiers corresponding to each type of comments are trained.

In the training stage, the occurrences of each word in the target and non-target comments in the training data are computed. The score of a word is computed by $s = (T - N)/(T + N)$, where T and N are the number of occurrences of the word in the target and non-target type of comments, respectively. In the testing stage, the score of a comment to be classified is computed as the average score of all the words in the comment: $\bar{S} = \frac{1}{M}\sum_{i=1}^{M} s_i$, where M is the number of words in the comment; s_i is the score of the ith word of the comment obtained from the training process. Only those words appearing in the training comments are considered. Once the score of each comment is computed, the content type of each comment can be determined using naïve Bayes classifier, which is a two-class Gaussian classifier in our case.

After analyzing the content of each time-anchored comment, the characteristic of a real learner is represented by a seven-dimensional vector formed by the numbers of comments the learner left in seven categories, respectively. Finally, k-means clustering is applied to group similar learners into same virtual classmates by using the Euclidean distance in the 7D space as the clustering distance, where k is the number of virtual classmates. Note that more sophisticated clustering methods can be applied to achieve better mapping. Also, the variety of the dataset of time-anchored comments may affect the mapping quality. It would be our future work to explore these issues.

3.2 Motion Mapping

To build realistic virtual classmates, we also analyze the emotional valence and arousal of each time-anchored comment and map a suitable behavior and response to the comment. We apply the approach of emotional analysis of comments in [36], which adopted a Naïve Bayes classifier to classify the valence of emotion of each time-anchored comment as positive or negative.

For the emotional valence classifier, its training and testing procedures are similar to those of the content type analysis approach described in Section 3.1 except that only the adjectives are considered when computing the score of each comment. The motivation of using only adjectives is inspired by Hu and Liu [20]. They determine the semantic orientation of an opinion-sentence by counting its positive and negative adjectives based on WordNet. Because WordNet does not support Chinese, Sung et al. [36] propose to use a two-class Naïve Bayes classifier to determine the emotion of a comment. After classification, the emotion of a comment is reversed if there is a negation word close to the adjectives (word distance less than five in our implementation), as suggested by Pang and Lee [31].

Similar to the emotional valence analysis approach, we also classify the arousal of each time-anchored comment, which represents the degree of emotional strength in text message, as high or low using a two-class Naïve Bayes classifier. For this arousal analysis, we used Yu et al.'s word library [43], which has calculated the emotional arousal of the included words, to label the training comments. Additionally, we invited seven graduate students to manually label the emotional arousal of some words or internet slang with consensus that appear in the training comments but are not in the library.

Finally, based on the results of the two classifiers for emotional valence and arousal, we can classify the emotion of comments into four categories: angry, sadness, joy, and relaxed (Figure 1). Then, according to the emotion of a comment, our system would randomly choose one motion from a group of emotional motions [39] in the same emotion category. For example, if a comment is classified as having angry emotion, our system would randomly choose a nonverbal emotional expression in the angry group of the database [39] and let the virtual classmate perform the corresponding emotional expression when speaking out the comment.

The motion database [39] contains more than 1400 clips of natural emotional body expressions in typical monologues performed by amateur actors. The emotion categorization of each clip from each of the eleven volunteering viewers are also recorded. In this study, our motion mapping only utilizes those motions which at least seven viewers agreed to label as one of the following categories: angry, sadness, joy, or relaxed. This makes the emotion of virtual classmates' body motions more congruent with that of the comments they present.

[1] http://www.makehumancommunity.org/

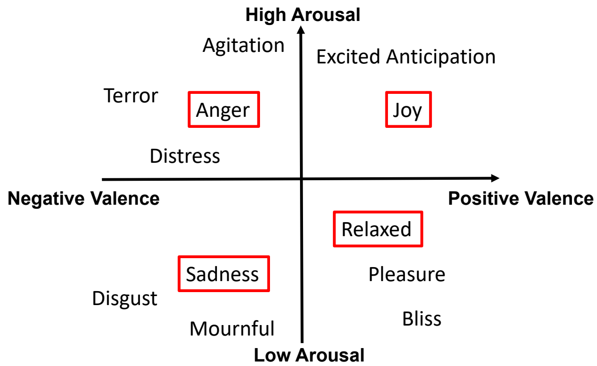

Figure 1: The four degrees of the emotions.

Figure 2: The scene of the experimental condition with 5 virtual classmates as learning companions.

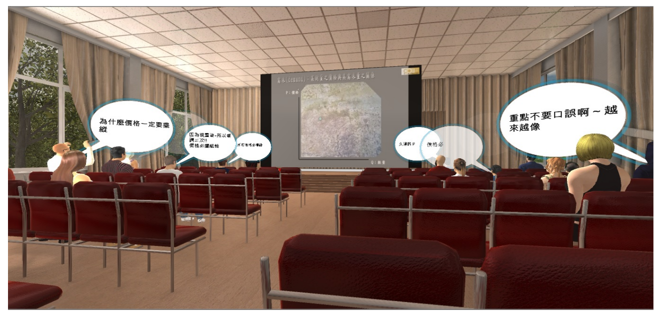

Figure 3: The scene of the experimental condition with 20 virtual classmates as learning companions.

4 Evaluation Study

We conducted a between-subject experiment in a lab setting. We chose a lecture video from an online economics course offered in a major university in Taiwan. The topic of the lecture is "Introduction to Economics" and its length is approximately 15 minutes long. The video, which aimed at undergraduates or novices, introduced fundamental concepts in economics, such as normal good, inferior good, luxury good, and the law of demand. This made it less likely that participants would abandon the lecture due to the difficulty of the subject matter. We collected learners' comments to this economics lecture using the time-anchored commenting system developed by Lee et al. [27]. A total of 413 time-anchored comments were collected by the system, and these comments were left by a total of 50 participants (21 females).

4.1 Research Questions

The goal of this study is to evaluate our system and particularly understand the influences of artificially synthesized virtual classmates and VR classroom on online learners' learning experiences. This study aims to answer the follow research questions:

RQ1. Would virtual classmates with comment mapping techniques influence the learning experiences of learners? One advantage of virtual classmates is the possibility of manipulating real learners' comments to construct the virtual classmates synthetically. How to create virtual classmates is a crucial issue. Prior studies have shown that the contents of peer comments would influence people's emotion and behaviors. In [7], the trolling behavior in social media increased in discussion with negative mood and prior trolling posts. Besides, Lee et al. [27] also found social-oriented comments enhance learners' social interactivity perceived engagement in online courses. Hence, it is likely that the manipulation of the contents of virtual classmates' dialogues would influence learners' learning experiences and behaviors. We would like to know how virtual classmates with comment mapping would influence learners' learning experiences and behaviors.

RQ2. Whether and how the number of virtual classmates influence the learning experiences of learners? Based on prior works [5, 26], the presence of peers in online learning has been seen as a crucial factor to engage learners in courses. However, in the VR environment, the number of people that a learner can interact with would be limited by the space constraint and first-person perspective. It is likely that an online learner cannot absorb too much information from peers and even consider peers' feedback as disturbances during learning. Since very few works have studied this issue in the past, we would like to explore how the number of virtual classmates affects learners in a VR learning environment.

4.2 Experimental Factors

In our experiment, we examined the effects of comment mapping (with versus without) and number of virtual classmates (20 versus 5). In the with-comment-mapping condition, virtual classmates would generate certain categories of comments more frequently due to the clustering of comments, e.g., taking more notes or raising more questions in the class. In the without-comment-mapping condition, the comments were randomly grouped and assigned to individual virtual classmates regardless of comment types. As for the number virtual classmates, participants were randomly assigned to 20-classmate or 5-classmate conditions. The condition with 20 virtual classmates is considered to be more crowded than having only 5 virtual classmates, simulating a larger class in real-world classrooms.

We explored the impacts of these two factors on the user's learning and experience in a total of four conditions (C1-C4): (with or without comment mapping) x (20 or 5 virtual classmates). Moreover, to evaluate the influence of a VR classroom, we added a non-virtual-reality environment (C5) as the baseline condition, in which text-based time-anchored comments were dynamically displayed using the system proposed by Lee et al. [27]. Figures 2-4 show the scenes of experimental conditions. The five experimental conditions are listed below:

C1: 5 virtual classmates with comment mapping (5M)
C2: 5 virtual classmates without comment mapping (5R)
C3: 20 virtual classmates with comment mapping (20M)
C4: 20 virtual classmates without comment mapping (20R)
C5: Time-anchored system (non-VR environment)

4.3 Participants and Procedure

We recruited 100 participants (54 females, aged 18 to 35 years old, M=22.7). All of them had prior online learning experiences on public online learning sites, such as Cousera, Udemy, Youtube, etc.

Figure 4: The scene of the experimental condition of C5: non-VR environment.

Most of the participants were not familiar with the topic to be learned in the study (93% of them scored less than 50 points out of 100 in the pretest).

Before the participants started to watch video clips, we briefly introduced the experiment procedure, including the course video they would watch, and asked them to take a pretest. Then, we explained the system interface, and in the VR classroom condition (C1-C4), we would assist the participants to wear head-mounted display and confirmed that the participants did not have any discomfort before starting the class.

Although the time-anchored commenting interface proposed in [27] allows participants to leave comments, we disabled this function in all conditions in this study. The reason is that entering comments in VR without using voice input or other special interfaces is inconvenient and can complicate the experimental tasks. After the participants finished the video lecture, they would take a posttest. At the end of the experiment, all participants were asked to complete a questionnaire and an interview to share their experience about the system. An experiment usually took one hour and the participants would get a small amount of money for incentives.

4.4 Equipment

The VR device we used is the Oculus Rift DK2 with 960 x 1080 resolution per eye and 72 Hz refresh rate. The system was running on a PC with Microsoft Windows 10 operating system, Intel Core i7-6700K processor, 32GB RAM, and NVDIA GeForce GTX 1070.

4.5 Measures

To analyze the participants' learning experiences and behaviors from different perspectives, we utilized three types of measures, including objective measures of learning achievements by pretest and posttest, subjective measures of perceived social interactivity and focus attention by survey questionnaire, and further understanding of learning experiences by interview.

Learning Outcomes. We used the difference of subtracting pretest from posttest scores to measure a participant's learning outcome. The questions in both tests are conceptually equivalent, but the orders and descriptions of these questions were modified. Each test has ten questions and each question counts ten points. The questions were designed based on the course content of the video clip the participants watched, such that participants should have been able to answer these questions if they had concentrated on the lecture. Two example questions of tests are: *"What is Normal Good? Please give a definition or examples."*; *"After the increase in income, what changes do we usually make to the consumption of normal, neutral, and inferior good?"*

Survey. To understand social and attitudinal influences of the participants, we designed a survey based on previous studies to measure perceived social interactivity [15,45] and perceived focus attention [30], which can be considered as learners' concentration on courses. The survey included 14 questions using a 5-Likert scale. To make sure that the participants conducted the survey seriously, we set two questions which are with similar meaning to judge the Lie scales. The survey questionnaire is provided in the supplemental materials. Below are two question samples:

"I was absorbed in the learning task." (Focus Attention)

"I would like to maintain social relationships with classmates in class or pay attention to their news feed." (Social Interactivity)

Interview. To supplement the qualitative data, we interviewed the participants face-to-face to further understand their learning experiences. The interviews focused on three issues: (1) user experiences of our system, (2) the influence of comment mapping, and (3) the influence of the number of the virtual classmates.

5 Results

Although the participants could freely choose and change their seats during the experiment, their distances to the lecture video did not vary much as the mean and standard deviation of the distances are 4.05 and 0.29 meters, respectively. There is not much evidence that the distance from learning materials would confound with other experimental factors.

Following the standard data analysis procedure as recommended in [23], we removed the outlier data by excluding scores that are outside the band around the mean with two standard deviations for each of the dependent measures, i.e., z-score greater than two, before analyzing each measure.

5.1 Learning Outcomes

After removing the outliers, the numbers of participants for conditions C1 to C5 were 18, 19, 19, 18 and 20, respectively. We computed one-way ANOVA with learning outcomes (i.e., posttest minus pretest scores) as the dependent variable and experimental condition as the independent variable. A Scheffé Test was used for the post-hoc analysis.

Figure 5 shows the results of leaning outcomes. We found that C1 (M=71.28, SD=2.872) had significantly better learning outcomes than C2 (M=55.47, SD=4.371) and C3 (M=59.58, SD=3.491), marked by the green lines in Figure 5. Also, we applied t-test to analyze the relationship between conditions. The results show that C1 had significantly better learning outcomes ($p<.05$) than C5 (M=60.3, SD=4.485), marked by the gray line in Figure 5. Besides, we also performed two-way ANOVA, where comment mapping, the number of virtual classmates, and the interaction between the two factors were include as independent variables. There was a significant interaction effect between number of classmates and comment mapping on learning outcomes ($F(1,70)=6.742$, $p=0.01 <.05$). Overall, we found that if there were only five classmates, comment mapping would give more help to the participants (C1 > C2, C3, and C5, please see Figure 5 for p-values).

5.2 Social Interactivity

For the analysis of social Interactivity, 19, 19, 20, 18 and 20 participants in each condition were included in the analysis after outlier removal. Since C1-C5 failed to pass the homogeneity test, we chose Welch's ANOVA to analyze the social interactivity. A Dunnett's T3 test was used for the post-hoc test.

The social interactivity score of C1 (M=2.9181, SD=0.14035) was significantly lower ($F(1,35)=4.550$, $p=0.040$) than C4 (M=3.3395, SD=0.17797). This finding indicated that participants learning with 20 classmates who had no comment mapping would perceive more social interactivity than participants with 5 classmates who had comment mapping. The results of social interactivity are shown in Figure 6.

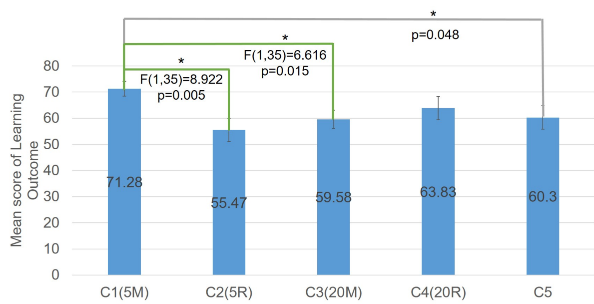

Figure 5: The results of learning outcomes.

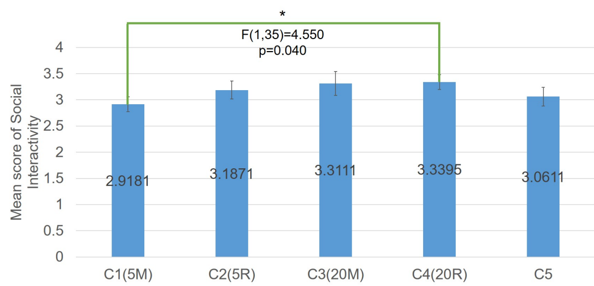

Figure 6: The results of social interactivity.

5.3 Focus Attention

In focus attention, 18, 19, 19, 18 and 20 participants were included in conditions C1-C5 respectively after the outlier removal procedure. Since the measurement results in C2 (M=3.5972, SD=0.11635) did not fit the normal distribution, we used non-parametric statistics [19]. We computed Welch's ANOVA with focus attention scores as dependent variables and C1, C3-C5 as the independent variables. A Dunnett's T3 test was used as well.

We found that the difference between C3 (M=3.87, SD=0.15) and C5 (M=3.36, SD=0.20) approached an acceptable level of statistical significance (p=0.054). The result implied that participants learning with 20 classmates who had comment mapping felt more concentrated than participants who did not wear VR. We show the results in Figure 7.

5.4 Interview

For analyzing the results of interviews, we invited two experts to open-code the interview transcripts to identify salient themes emerging from the interview conversations. We report the interview results

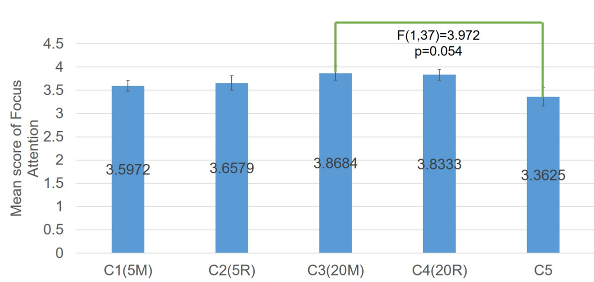

Figure 7: The results of focus attention

in the following paragraphs.

The effects of VR classroom. First, more than half of the participants (57.5%) in C1-C4 reported that in our VR classroom with VR classmates, which is different from general online courses, they felt they were taking courses in a real classroom. The feeling of presence and existence of virtual classmates makes the participants feel the course more interesting.

> *"You can see what the classmates next to you were doing. That is a feeling that you were in the classroom or inside."* (S2, C2)

> *"Just like the experience, it made me feel less like a general online course where I was alone."* (S76)

> *"You can see the comments from your classmates, and then you feel immersed. It is not just seeing the comments next to a film. I may see that the words were from the classmate on the left, or the classmate on the right."* (S80, C4)

Besides, around 73% of participants in C1-C4 mentioned that they were more concentrated in the VR classroom because of the isolation from the real world and external disturbance. In contrast, there are only 30% of participants in C5 agreeing time-anchored comments could maintain their attentions in the class.

> *"I can be isolated from the outside world. The benefit may be quieter and then I was not disturbed by the outside"* (S16, C2)

Finally, we also asked the participants' willingness of leaving comments if we added the comment-leaving function in the future. We found 65% of participants in C1-C4 reporting that they would like to leave the comments for participating and joining the discussion in the class. In contrast, there are only 30% of participants willing to leave comments in C5.

> *"It's more like having a group of people to attend the class with you than watching a video alone, and someone can discuss the content of this course with you."* (S60, C1)

> *"I think I will be more immersed into this class, because when they were speaking, I really wanted to speak."* (S14, C4)

The effects of comment mapping. In C1 and C3, 55% and 33% of participants reported that with the comment mapping technique, they can quickly seek out the comments they need by focusing on specific classmates who inclined taking notes or raising opinions.

> *"Because it will be ... to know whom you should look at when you want to find the key points, and it is not needed to care about the others."* (S19, C1)

> *"I think it's better now. Just as long as it is...if you think who is more helpful, you can just look at him/her."* (S93, C1)

In contrast, in C2 and C4 without comment mapping, there are more than half of the participants (around 55%) mentioning that they met the difficulty to find the information they want to see.

> *"The classmates' comments were sometimes too dense, and then I didn't know where to look."* (S70, C2)

> *"What I didn't like was that sometimes the comment appeared and it attracted my attention. However, after I reading it, I thought it was totally nonsense."* (S20, C4)

The effects of number of classmates. We asked if the number of virtual classmates had impact on their learning experience and whether they wanted more or fewer virtual classmates. Most of the participants did not feel the numbers of virtual classmates are uncomfortable in conditions C1 to C4, suggesting that the size of virtual peers may not play a major role in shaping learners' experiences of learning

6 Discussion

6.1 Summary of findings

First, we found that when learning with fewer virtual classmates using the comment mapping technique, online learners had better learning outcomes than those without comment mapping. Besides, according to the results of the interviews, there were 55% of participants in C1 mentioning that they could easily focus on certain virtual classmates and acquire the comments they needed when comment mapping is implemented. In contrast, learning with more classmates (i.e., 20 virtual classmates) constructed with comment mapping did not enhance a learner's learning outcomes. The reason might be that it became difficult for the participants to seek out the expected comments when many virtual classmates expressed their comments at the same time or the comments were distributed more broadly when there were more classmates. Therefore, the effect of comment mapping might become less influential as what we observed in C4.

Overall, we observed that the commenting mapping technique could successfully help learners acquire needed information and obtain better learning outcomes. However, the effect of comment mapping may be moderated by the number of virtual classmate since learners have their limitations to interact with a large amount of avatars.

In terms of social interactivity, surprisingly, we found that learning with 20 virtual classmates without comment mapping resulted in significantly higher social interactivity than learning with 5 classmates with comment mapping. We considered that the reason may be related to the effect of comment mapping, since the participants in C1 might spend more time focusing on the classmates who mentioned course-related comments than those in C4. Therefore, they reduced their social interactions while their learning performance was improved.

Finally, the results showed that participants had higher focus attention in C3 than in C5. Through the interviews, we also found that more than half of the participants in conditions C1 to C4 reported that learning in VR classroom could help them maintain their focus to the course. It could be that the realistic feeling of learning in the VR classroom and the isolation from the outside world lead people to concentrate on the lecture. Besides, according to the interviews, VR classroom and the appearance of virtual classmates increase the learners' motivation to leave their comments and join the discussion.

6.2 Design Implications

Synthesizing virtual classmates with real learners' comments can influence the ways people learn in virtual environments. Our findings indicated that, with small number of virtual classmates, comment mapping technique which sorts similar information into specific classmates can help learners effectively focus on specific types of information and then enhance their learning outcomes. However, we also note that designers should consider the trade-off between learning experiences and social interactivity since our result also indicated the effects of comment mapping might lower learners' perceived social interactivity. If we could detect the learning status of online learners such as the reduction of social interactivity or lost of comprehension, dynamic manipulation of classmates' comments would be helpful in different conditions. Hence, we suggest designers utilize real-context feedback to create virtual classmates and especially manipulate the content types of virtual classmates, e.g., highly course-related or just general conversation [27].

The number of virtual classmates should be considered for learners' possible limitation in handling multiparty interaction in VR environment. The size of virtual classmates influences different perspectives of learning in our study. First, our results showed that, in contrast to having fewer classmates, when learning with more virtual classmates, learners cannot take the advantages of comment mapping and might be harder to seek out helpful information. However, we also found that learners had higher social interactivity when learning with more classmates without comment mapping technique. Since the comment mapping technique is one of the methods to construct virtual classmates, we suggest designers carefully decide the number of virtual classmates based on their goal of design. For example, it might be appropriate to apply fewer classmates if the goal is to enhance learners' learning outcomes.

VR classroom could make learners more concentrated and more willing to join the class. Similar to the previous works [16, 28, 38, 44], we also found that learners in VR environments would become more attentive and feel more immersed because of the realism of VR classroom and isolation from outside world induced by the VR devices. Moreover, learning in a VR classroom with virtual classmates can enhance learners' willingness to share their opinions to the class. Hence, we suggest that the VR classroom and virtual classmates are suitable way to improve online learning experience in the future.

7 Limitations and Future Works

We discuss the limitations and future work of this study. First, we only explored a very small design space of virtual classmates and VR classroom. Besides comment clustering, there is certainly more room for adopting other mapping functions to improve the characteristics of virtual classmates. For example, we may filter out negative comments or utilize the prediction of a learner's learning status to give appropriate comments to him/her promptly. Moreover, we may raise questions or reply to learners to stimulate more class discussions and thus help learners reflect to gain deeper understanding of the content [37]. Improving comment mapping by further manipulating real learners' feedback is worth of further exploration in the future.

Second, we still need to identify clearer influence of the number of virtual classmates on online learners in VR classrooms. Our current findings suggest that possibly because of the learners' limitation of interacting with multiple virtual classmates, learning with fewer classmates could strengthen the benefits of comment mapping; however, on the other hand, learning with more classmates seemed more beneficial to learners' social interactivity. Since creating virtual classmates could be costly, the understanding on the effects of the number of classmates becomes important as a next step.

Third, in terms of VR classroom system, we will improve it with features of social interactions, such as leaving comments and observing its influences on learners' learning behaviors since we saw the high willingness and expectation of our participants to interact with virtual classmates. Furthermore, if a comment leaving interface that can reliably and handily fit in the VR environments, e.g., voice input or mid-air keyboard, is available, we can investigate the influences of other design or contextual factors to learners, such as course contents and learners' level of familiarity and distance to the lecture videos, in the future

Finally, the current study is limited by its laboratory setting, which may render limited external validity with the results. In the future, we will seek opportunities to conduct the study in the field, e.g., learners at home logging into a VR classroom. We would also like to run a longitudinal study to see if virtual classmates could help to retain learners over time, and we predict that a social rich environment like what we are doing is likely to do a better job in student maintenance. Besides, for online learning courses that could span few weeks, by adjusting the number of virtual students and toggling comment mapping based on learners' status and feedback during their learning process, we think it is possible to improve both learners learning experiences and completion rates.

8 Conclusion

In this research, we design a VR classroom for online learning and propose a comment mapping method to analyze and assign real learners' time-anchored comments to a limited number of virtual classmates. To examine the effects of synthesized virtual classmates and VR classroom, we manipulate the number of the virtual classmates and comment mapping to understand their influences on learners' learning outcomes and overall experiences. The results suggest that comment mapping is helpful when the number of classmates is smaller (five). On the other hand, having 20 classmates without comment mapping could help improve social interactivity. We believe the comment mapping approach proposed in this paper could enhance online learning experiences and the comment mapping concept could stimulate future research on the virtual characters in the context of online communities.

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