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Work in Progress: Exploring the Method to Design an Equal Engineering Class Environment for Students' Collaborative Learning under Head-mounted Display Virtual Reality (HMD VR) Condition

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Introduction

HMD VR has gained increased attention in last two years. Especially in the engineering education field, it enables users to be fully immersed in a 3D simulated engineering workplace overcoming the time and place limitation [1]. This characteristic is welcomed by engineering faculties, who have used various HMD VR applications to facilitate their class instruction. However, inequitable phenomenon may exist when students participate in learning activities under HMD VR environment [2]. A typical case is reported by Kolomaznik, Sullivan, and Vyvyan [3]. In a first-year science communication class, students were self-organized into small groups of four to six people to play a maze game. The role settings in the game were that one student in a group played the game with HMD headset while others directed the player with a map outside the VR environment. The post-test survey results show that one in five students frequently observed dominating behaviors from their team members in this activity. Intuitively, this activity design is problematical. Since only one HMD headset was available in a group, it would be hard to avoid unequally accessing this learning resource among students. However, we are not sure whether this intuition is right; if it is right, to which extend this design will cause inequity; whether this inequity will affect students' performance and learning outcomes; what are the design principles when we prepare similar activities with equity and maximizing the potential of HMD VR in engineering education.

Global VR in the education market is expected to grow at a speed of over 55% per year from 2017 to 2021 and VR facilitating collaborative learning is one of the top emerging trends driving the global VR in the education market [4]. Identifying the answers to these proposed questions will facilitate the implementation of collaborative learning with VR in education and cultivate broader beneficiaries.

Dominating behaviors are regarded as the main pattern of inequity in collaborative learning. Prior research has explored its harm to students' learning, the reasons that lead to these behaviors, and related solutions. However, there is lack of research that explores how to minimize these behaviors and design an equal learning environment for students in a computer-supported, especially HMD VR-supported, class.

This proposed study is expected to fill the gap. Being motivated from the activity described in [3], I will conduct a research to explore whether the dominating behaviors can be eased when more HMD headsets are available for a team in a collaborative learning activity and what are the design principles of an equal learning environment for collaborative learning under HMD VR environment. The research question that leads the study is:

How to design an equal engineering class environment for students' collaborative learning with HMDs?

To answer the research questions, I plan to conduct an experiment to examine students' performance and learning outcomes under HMD VR environment for a collaborative virtual engineering assembly task. In this research, hypotheses will be proposed based on literature first, then experiment-relevant instrument and VR application will be developed. After that, the experiment will be implemented. Students' performance data in the experiment and their responses to the pre-and-post-experiment surveys will be collected and analyzed.

Simulated object assembly experiment (e.g., building, machine, and circuit assembly) is frequently used in classroom instruction by engineering faculties. It has been recognized for its ability to increase the effectiveness of instruction and students' learning as it help students relate classroom material to real-life engineering problems [5]. An empirical investigation of its collaborative learning activity design under the HMD VR environment is not only of research value as it contributes to the knowledge on the effectiveness of HMD VR environment in collaborative learning but also expected to benefit different stakeholders in the engineering education systems. Students born in the new century will start to attend universities in 2018. They are a new generation that grew up with digital media and are eager to acquire the similar experience in the class as their daily life. This requirement urges engineering faculties to accelerate the application of new information technologies in their instruction [6], [7]. The results of this study are expected to serve as a practical reference for engineering faculties to apply new technologies in their instruction. Conversely, a well-designed learning activity will motivate students to learn with higher interest and better master both engineering and professional skills. Lastly, an equal engineering class environment will contribute to the solution of students' retention in the engineering disciplines and promote a diversity of work force in the engineering field of the United States [8].

Literature Review

Collaborative learning

"Collaborative learning" is an umbrella term for a variety of educational approaches (e.g., discussion groups, peer teaching, learning community), which emphasize the joint effort of team members for a mutual learning goal [9]. The participants can be students, or students and teachers together [9]. This learning approach represents a significant shift from a traditional instructor-centered to a student-centered learning [10]. It can effectively promote students' learning motivation, enhance critical thinking, and inspire innovation [10], [11].

Due to the differences of focus level (i.e., individual, small group, community), the definitions and the theoretical foundations used for collaborative learning research are various. In this research, the lens of collaborative learning is: students in a team of two to six members synchronously work on a specific educational task. In the process, they mutually construct and maintain a shared knowledge for the success of the task. The focus will be at the individual unit, where the collaboration is an external intervention under a specific context.

Equity in small-group collaborative learning

Collaborative learning is widely recommended as a method of creating equity in the classroom instruction [12]. It advocates simultaneous interaction, positive interdependence, individual accountability and equal participation [13]. However, dominating behaviors (e.g., speaking loud and prevent others from speaking) were still observed and recorded in collaborative learning activities at school [14]. These behaviors seriously reduced the knowledge acquisition opportunities for the teammates and negatively affected the whole team's performance [12], [15]. Generally, there are two reasons that lead to this type of behaviors in collaborative learning. One is the individual students' potential bias towards teamwork [16]. In their view, interactions with others are contests while acts of aggression are signs of strength that garner respect [15]. The other is related to the status differences [17]. Specifically, high-status students (e.g., academic score, popularity) who take personalized power orientation tend to dominate group interaction for advancing personal concerns [18]. Instructors' supervision and open-ended tasks are regarded as effective methods to solve this issue [19], [20].

Collaborative learning with VR environment

Although researchers have proposed different approaches to cultivate equity in collaborative learning, there is little research that has explored the issue of equal access to resources in a collaborative VR learning activity. This phenomenon has formed a strong contract with the present hot wave of exploring the STEM educational potential for multi-user virtual reality environment [21].

In general, there are two types of participants' settings for a HMD-based collaborative task: one is that all the members are in a shared virtual environment with HMDs, the other is that only one member in the HMD VR environment and the other members vocally direct this member outside. In the following statement, the first type of role setting is named full-immersive, and the second is semi- immersive. Based on literature, hypotheses related to the comparisons between students in the full- immersive teams and the semi- immersive teams are proposed. These hypotheses are under the pre-condition that there is no significant difference in the background (e.g., academic score, gender, race) between students in the two groups.

Students' experience under VR environment

Social presence (or co-presence) is defined as a person's sense of being in an environment together with other users [22], [23]. This sense is critical to promote collaborative learning and knowledge building [24]. Perceived being interdependent with others are the top level of social presence [25]. The specific behaviors can be helping and receiving helps from others, being connected to, and responsive to others [10], [25]. Since having their own HMDs and the condition for everyone to act and interact in the VR environment is equal, the sense of social presence should be more evenly among students in the full- immersive teams than in the semi- immersive teams. On the other hand, since only one student in each semi- immersive team implements the task in the VR environment, ideally, there will be more frequent vocal communication and close emotional connection among team members than in the full-immersive teams. Therefore, students in the semi- immersive teams should have a higher level of social presence than in the full-immersive teams.

H1: The social-presence among students in the full-immersive teams will be more even than students in the semi- immersive teams.

H2: The social-presence among students in the semi-immersive teams will be higher than students in the full-immersive teams.

However, a higher level of social presence does not always result in better outcomes [26]. The presence of dominating behaviors would be detrimental to the whole team's performance due to lower consistency among members in a team [15]. Additionally, sufficient HMD headsets enable all members in a full-immersive team simultaneously assemble the virtual automobile for the task. Since the time spent to complete the task is the metric of students' performance in the task, students in the full-immersive teams should spend less time to complete the virtual automotive assembly task than students in the semi-immersive teams.

H3: Students in the full-immersive teams will spend less time to complete the virtual engineering assembly task than students in the semi-immersive teams

Students' learning outcomes

According to Sweller's Cognitive Load Theory [27], collaborative learning under VR environment includes two sub-tasks: one is constructing the knowledge and the other is controlling the learning environment [27], [28]. If the external environment enables more efficient interaction, communication, and control, users will correspondingly focus more on learning itself, which leads to better learning efficiency [28], [29]. In this experiment, HMD shields the unrelated visional disturbance from outside and concentrates students on the task under a shared virtual environment for the full-immersive teams [30]. Therefore, they should have more knowledge gains after the task than in the semi-immersive teams

H4: Student in the full-immersive teams will have more knowledge gains after the virtual engineering assembly task than students in the semi-immersive teams

Furthermore, unequal participation leads to different learning gains (e.g., who talks more, learns more) [12], [17]. Specific to the learning under VR environment, the level of immersion is an indicator of better learning and potentially higher learning transfer when other conditions are the same [28]. Therefore, the student that plays under the HMD VR environment will have more knowledge gains than his or her teammates in the semi-immersive team. Similarly, the knowledge gains among students in the full-immersive teams should be more even than in the semi-immersive teams as all members are immerged in a shared HMD VR environment.

H5: students serving as “player” will have more knowledge gained than his or her teammates in the semi-immersive teams

H6: the knowledge learning gains among students in the full- immersive teams should be more even than in the semi- immersive teams.

Finally, interactive competition generates negative attitudes toward the group, and hence toward its members [31], In the semi-immersive teams, the limited number of HMD headsets leads to competition for the role of player and further prompts an increase in dominating behavior [3], while each students in the full-immersive teams are equipped with the same HMD headsets. Thus, students in the semi-immersive teams will take more negative attitudes towards the collaborative learning after the task than in the full-immersive teams.

H7: Students in the semi-immersive teams will take more negative attitudes towards the collaborative learning after the task than in the full-immersive teams.

Methods

This research will employ a mixed methods of convergent parallel design with an emphasis on the quantitative data (QUAN + qual) [32]. Although there still lacks of agreement on terminologies in the mixed methods study field, a combination of the quantitative and the qualitative research strands is regarded as the most important characteristic of mixed methods research by all researchers [33]. Triangulation and complementarity are the two reasons for conducting mixed methods research in this study. In other words, I will seek both validation and enriched understanding of the quantitative conclusions from the qualitative results through this design [34].

A typical convergent parallel design mixed methods study has independent qualitative and quantitative strands [32]. Data collection and analysis for these two types of data are concurrent but separate. Once researchers have the initial results from the two sets of data, they will start to merge these results and find the convergences and divergences. Finally, the researchers will interpret the analysis results and create a better understanding for the overall research.

The research will be conducted at a large public university in the Southwest. In this research, students’ performance and learning outcomes in a virtual automotive assembly task will be examined under two conditions: full-immersive team and semi-immersive team. The quantitative data will be gathered from the closed questions in two surveys and the process of experiment; the qualitative data will be from the open-questions in the post-experiment survey.

Participants

The target participants for the experiment will be approximately 40 undergraduate engineering students at a large public university in the Southwest. If the number of registered students is less than 30, the recruitment time will be extended. If the number of registered students is more than 50, the priority of participants will be representative students based on their background. In this situation, the final participants will show a diverse population in engineering disciplines, grades, gender, race and ethnicity.

Instruments Development

Two questionnaires and one VR application will be prepared for this research. The first questionnaire will be for the pre-experiment survey. The main content in the questionnaire will be demographic questions, instruments of personal attitude towards teamwork, and a quiz of automotive assembly. The second questionnaire will be for the post-experiment survey. Besides the content in the first questionnaire, this questionnaire will include the instruments of social presence and the supplementary open questions related to participants' experience in the collaborative virtual assembly task, their reflections, and feedbacks.

The development of these two questionnaires will follow the instrument development process in the affective domain introduced by McCoach, Gable, & Madura [35]. Specifically, four steps will be completed in sequence: (1) literature reading and existing similar instruments search; (2) item writing or revision; (3) content validity assessment; (4) face validity assessment. Two or three researchers in the engineering education and the automotive fields will be invited to assess the validity of generated items and 3–5 undergraduate students to evaluate whether the instruments can be understood for the face validity assessment.

In addition, the content of the VR application will be related to a virtual automotive assembly task. Its purpose is that players will be familiar with the internal structure of an automobile after the virtual task. The application has two modes: single player and team work. The team-work mode supports at least three players wearing HMDs to assemble one virtual automobile at the same time in a shared virtual reality environment. The initial scenario of this application is that all the components (approximately 30 pieces) of an automobile are scattered on the floor. In the single player mode, when the player pushes the start button, he or she can start to move these components and assemble the automobile. In the team-work mode, after all players push the start button respectively, they can start to assemble. In the team-work mode, all the players can synchronously see the work of other avatars from a first-person view. An embedded clock is used to record the time that player(s) complete the assembly task. Researchers in the engineering education and the automotive fields will be invited to examine the validity of the application, and whether the quiz designed in the questionnaires can correctly reflect students' knowledge gains in automotive assembly after students participate in the virtual assembly task.

Data Collection

All recruited students will be randomly assigned into 4-member teams and all the teams will be evenly assigned into one of the two experimental conditions. Each team will be invited to the VR laboratory to participate in the experiment independently based on prearranged time. After all the team members arrives at the laboratory, I will briefly introduce this research and the experiment rule. Then they will fill out the pre-experiment survey and sign their names on the consent form. When all the team members have submitted their surveys and contract forms, the experiment phase will start: assemble the components of an automobile in the VR environment as quickly as possible. The teams that belong to different conditions have different experimental design. All members in a full-immersive team will wear HMDs and be situated in a HMD-based fully immersive VR environment with team-work mode. Only one member in each semi-immersive team will have opportunity to wear HMD and be situated in the HMD-based fully immersive VR environment with single-player mode, others will observe this member's operation in the VR environment through outside computer screen and vocally direct this member. When they successfully assemble the automobile, the experiment is finished. They will be given a 10-minute break, and then the post-experiment survey.

Data Analysis

Quantitative Strand: Missing data will be examined first. After that, independent samples T test will be used to evaluate whether there are differences in pre-experiment scores between students assigned in different conditions. If the results indicate no significant difference, further hypotheses testing will be conducted; otherwise, experimental data will be collected again with a revised sampling method. Next, independent samples T test will be used to test all the proposed hypotheses respectively. The data is from students' score in the post-experiment survey. More specifically, the hypotheses H1 and H6 will be examined by the method of Levene's test for equality of variances, and the hypotheses H2, H3, H4, H5, H7 will be examined by t-test for equal means. In these above analyses, once $p > 0.05$, the tested hypothesis will be rejected.

Qualitative Strand: Students' responses to the open questions in the post-experiment survey will be coded in two cycles. The initial coding method [36] will be applied in the first cycle of coding. It will first break down qualitative data into discrete parts with labels, and then build categories based on their similarities and differences [37]. Its strength is to "remain open to all possible theoretical directions suggested by researchers' interpretations of the data" [38]. The second cycle of coding will purposely center around the themes of the examined hypotheses in the quantitative strand.

Mixed Analysis: After the independent data analysis in both the quantitative and the qualitative strands, I will merge the results of the two data sets and interpret how they converge and diverge from each other. This analysis will elaborate the initial findings of the quantitative strand. At last, the design principles of an equal learning environment for collaborative learning under HMD VR environment will be proposed.

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