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Robot with Embodied Interactive Modes as a Companion Actor in Journey of Digital Situational Learning Environment and its Effect on Students' Learning Performance

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Abstract: When learning in a drama for situational learning, students need to solve the simulated problems encountered in the real world and may need a companion to guide and help them finish the drama journey. Due to the engagement, real-time feedback, and curiosity that a robot can bring, it can become an interesting actor companion to make drama performance more attractive. Additionally, physical interaction offered by the robot can make students learn through embodied interactions according to the situation and time. Therefore, this study proposes a learning approach, where student actors and the robot are immersed in digital drama scenarios, play drama, and interact with robots, scenarios, and virtual objects inside the digital situational learning environment. To evaluate the effectiveness of the proposed approach, a quasi-experiment was conducted in an English as a second language course for junior high school students. Three classes of students were assigned with different experimental instructions of learning with a robot actor in a situational learning environment. The experiment results showed that a tangible robot with more interactions significantly impacted students' learning performance. Questionnaire results revealed that students' learning motivation and engagement were improved when a robot actor with embodied interactive modes, including context-related oral interaction, touch interaction, and gesture interaction, was employed inside the digital situational learning environment.

Keywords: Digital situational learning environment, drama-based learning, situated learning, social robot, human-robot interaction, embodied interaction

1. Introduction

According to the situated cognition theory, learning should be contextualized and should not neglect the application of acquired knowledge in daily life (Brown, Collins, & Duguid, 1989). The critical characteristic of situated learning is to provide an authentic environment (Herrington & Oliver, 1995). Some previous studies demonstrated that students could effectively connect the action and knowledge of real situations when the environment of learning is similar to the actual world (Fadeeva *et al.*, 2010). As reality technologies (such as a 2D/3D scenario, Virtual Reality, and Mixed Reality) continue to develop, teachers or publishers can more easily integrate authentic scenes and scenarios pertinent to learning activities into a classroom.

Rousseau (1817) presents *learning by dramatic doing*, in which employing drama in the learning approach was introduced. Using drama in learning with a realistic environment and role-playing allows students to experience and implement their knowledge acquired from drama activities situationally. Several studies combined digital reality technology to build a digital situational learning environment (DSLE) for students to learn through drama performing and script designing (Cai *et al.*, 2020; Liu *et al.*, 2017; Wang *et al.*, 2020). It can assist teachers to build various digital authentic scenarios in accordance with textbooks to enable students to perform situational learning inside the classroom.

However, when performing situational learning, the student actors may encounter problems and may not be confident enough. Student actors might not reflect and correct their acts immediately because no one would notice their mistakes, leading to poor performance of drama learning. Consequently, they might not learn the correct knowledge or learning materials from drama scripts. Additionally, in order to engage the audiences during drama performing, talented actors are required to show apparent affect and express situations effectively (Murphy *et al.,* 2011). However, students are generally not professional actors. The actors' engagement in drama performing and audiences' interest in watching may be reduced if drama activities do not engage in situational interactions. Thus, they might need a companion or a mentor to guide, evaluate, and help them finish the drama journey.

To address the aforementioned issues, the robots can be added and designed as an actor and companion in a DSLE. One of the reasons why the robots are needed for DSLE is the curiosity (Gordon, Breazeal, & Engel, 2015) and the ability to enhance concentration and learning interest (Al Hakim *et al., 2020*). Referring to Barab *et al.* (2010) transformational play and Vogler (2007) archetypes in a drama journey, the robots can play the role of the "messenger" to tell the student actors what and how they should do in a stage of the journey. Additionally, it can also role-play as a "threshold guardian" to evaluate and correct the mistakes of student actors during drama performance, so the student actors need to focus on learning materials embedded in the drama stage. Students might develop an increased level of learning motivation through the activity and be forced to study in advance to do well in the drama performance. Promoting students' learning motivation has been recognized as an essential issue since robust learning motivation can improve learning performance (Murphy & Alexander, 2000).

Furthermore, robots' tangible and physical interaction can make student actors learn through embodied interactions, such as physical touch and oral interaction (Barnes *et al.,* 2020; Saerbeck *et al.,* 2010), and also movement or gesture (Kanda *et al.,* 2004). By utilizing related techniques, users can easily develop robot programs and integrate AI cognitive services (*e.g.,* Google Dialogflow, Microsoft Azure) into the robot and DSLE. Therefore, the learning system may have multimodal interactions and rich sensory information. The students might be highly engaged if the learning context is in the interactive mode with rich sensory information (Barnes *et al.,* 2020; Chin, Hong, & Chen, 2014).

In this study, a learning approach is proposed by adopting a robot with embodied interactive modes as a companion actor and performing situational learning with student actors in the virtual world provided by a designed DSLE. To evaluate the effectiveness of the learning approach, a situational learning activity of an English as a second language course for junior high school students was conducted to compare the learning outcomes, motivation, and engagement of the students who learned using the DSLE with robot embodied interaction approach, the conventional DSLE approach, and the conventional robot instruction approach. This study proposed the following hypothesis: DSLE with robot embodied interactive modes can enhance learning outcomes, motivation, and engagement.

2. Literature Review

2.1 Reality-Assisted Learning Technology

Reality technology is nothing new nowadays, but related technologies have developed on several research for years. For instance, Microsoft released *Kinect for Windows v2* in July 2014 and provided a new version of its SDK for the platform (https://developer.microsoft.com/en-us/windows/kinect/). With motion detection technology, a virtual world with embodied immersion can be easily and quickly constructed. By standing in front of Kinect v2, users' body positions can be retrieved through skeleton coordinates, which enables their full-body elements immersed into the digital scenario and wearing digital props, costumes, or objects (Liu *et al.,* 2017). Furthermore, users can watch their images in real-time displayed on the screen and reflect their performance in the virtual world (Wu *et al.*, 2015).

Several studies extended the reality-assisted learning technology with embodied interaction to promote learning performance and enhance students' experience in situational learning inside the classroom. For instance, the study of Wang *et al.*, (2020) employed body movements and considered the impacts of social cognition inside the classroom. The study results revealed that the students could simultaneously get assessments and corrections in real time, which significantly promotes students' learning performance. Besides, the learning gains and enhancement of students' motivation can also be cultivated by using mechanisms of real-time spoken language evaluation (Cai *et al.,* 2020). However, human-robot interactions that allow students to have embodied interactions through tangible and physical interaction were not addressed in the aforementioned studies.

2.2 Learning Environment with Robots

Employing robots into the classroom environment enables robots to perform as learning partners (Kanda *et al.,* 2004) or teacher assistants (Chang, Lee, Chao, Wang, & Chen, 2010; Chin, Hong, & Chen, 2014), which mostly emphasizes having a positive impact on learning. Physical robot interaction can facilitate students to get instant feedback (Chang, Lee, Wang, & Chen, 2010). Barnes *et al.*, (2020) proposed a child-robot theater framework by employing several robots to engage elementary students. In the process of theater preparation, teacher and students or developers may need to set up the props, scenery, costumes, and the narrative in order to play theater in the most authentic way (Romero-Hernandez *et al.,* 2018). Mixed-reality can be an interesting option to build props and stages (Bravo Sánchez *et al.,* 2017), which are difficult to be obtained in reality according to the learning content (Liu *et al.,* 2017).

Regarding related mixed-reality technology, importing robots into mixed-reality environments can construct a hybrid physical-digital user interface, which can be beneficial for learning (Antle & Wise, 2013). For instance, the prior study of Chang, Lee, Wang, and Chen (2010) presented a RoboStage system by importing robots into authentic mixed-reality. They claimed that robots could make the learning activities more engaging and enjoyable, which consequently affected students' motivation. It also concluded that students have a stronger preference to interact with a robot than virtual interactions. Nevertheless, such robot interaction in mixed-reality technology aforesaid was constrained to the physical environment only. In other words, the robots were not involved inside the digital scenario tasks.

Cheng, Wang, and Chen (2019) presented a design framework to guide researchers or teachers in developing an immersive language environment by utilizing tangible robots and IoT-based toys. Each presented important key points of design principles and guidelines can be as references to build an immersive language environment. Such an environment allows learners to play with the IoT toys while being accompanied by robots that provide them with parent-like linguistic feedback but done in the target language. However, researchers did not address a digital situational scenario to provide learners an authentic context or virtual world quickly and easily inside the classroom.

3. System Design and Implementation

DSLE with robot embodied interaction is constructed to assist teacher and students learning inside the classroom. It enables students and a robot together to role-play in various situations and provides a real-time evaluation under the situation. The teacher can choose interaction modes and virtual objects to quickly design the digital scenarios based on textbooks' content and contexts and put learning materials inside the scenario. Learning materials (*e.g.,* keywords, actions, and postures) are applied in a scenario, and students must learn them so they can confront challenges within the journey stage.

3.1 System Architecture

In this study, the display interface of DSLE is constructed by C#, Windows Presentation Foundation (WPF), and .NET Framework 4. Xbox Game Bar is used for video recording during drama performances. In addition, Zenbo SDK is used to develop robot capabilities (*e.g.,* touch sensing, emotions, and mobility). Besides, to enhance the capabilities of robots, Microsoft Azure Cognitive Speech Services API and Google DialogFlow API were involved in managing the speech recognition. Also, Microsoft Kinect V2.0 and its SDK were adopted to extend robots' eyes for capture and recognize actors' body skeletons. The main control application and robot program are developed on the Android platform. All of the system components communicate through a socket connection.

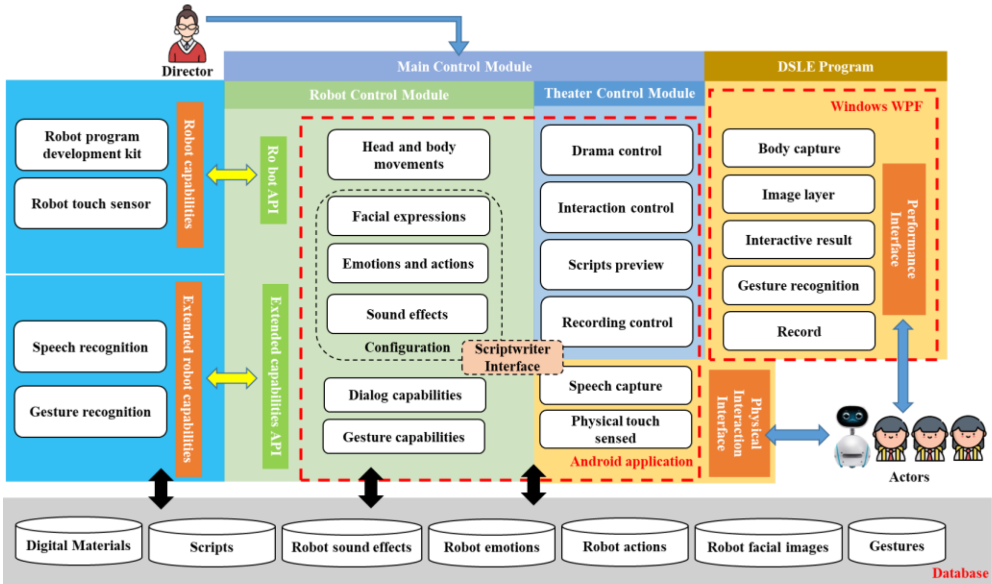

Figure 1. System Architecture.

Figure 1 depicts the system architecture of the study, which majorly consists of the main control module installed on a tablet, and a DSLE program installed on a personal computer with an NVIDIA graphics card. During drama performance, the teacher can situationally control the transition of digital scenes and the robot through the tablet. The main control module controls "Theater" (*e.g.*, scenes shift, interactions, scripts preview, display subtitles, and recording) and "Robot" (*e.g.*, head and body movements). Meanwhile, the DSLE program installed on the computer runs with Kinect v2 to capture actors' image and body skeleton information, and then construct a virtual world by combining scenarios with digital materials.

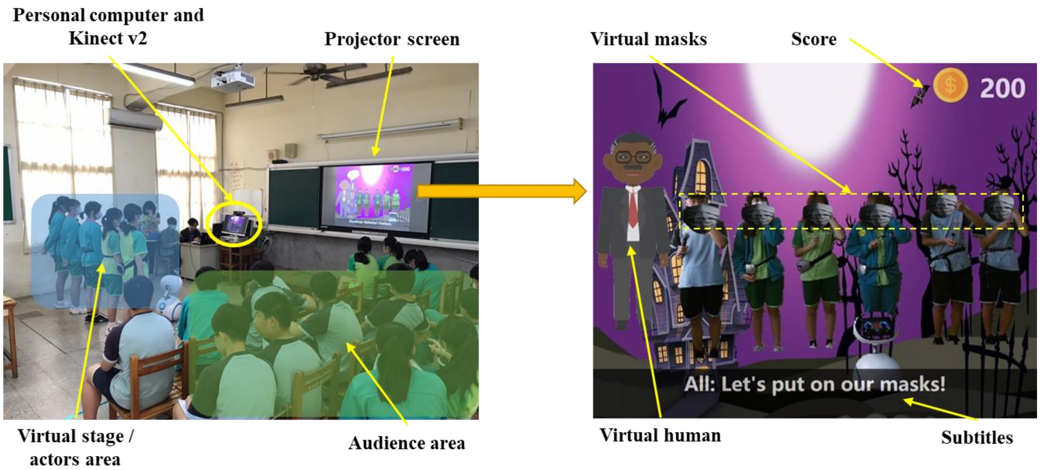

Figure 2. Composition of DSLE with Robot Embodied Interactive Modes.

Figure 2 displays the composition of the DSLE with robot embodied interactive modes. In this study, the classroom is separated into a virtual stage area and an audience area. By standing in front of Kinect v2, the robot and a group of student actors are immersed into the digital drama scenarios, play drama, and have interactions with a robot, scenarios, and virtual objects inside it. Student actors can watch their own performance and get instant feedback from the robot and virtual world through a computer screen, so learning activities become interactive. The computer screen in the virtual stage area is projected to the screen in the audience area, so the rest of the students can watch and learn actor performances through live broadcast. The learning system through the computer screen will display the virtual world and the task or mission based on script design to encourage actors to move, act, and speak narratively.

In order to make the robots able to do the same actions as student actors do, system communication of DSLE is extended by adding a database host system with robot materials (*i.e.*, sound effects, emotions, actions, facial images). By doing so, the robot can connect with the main control module on the tablet and DSLE program through socket communication. Consequently, before drama performing, the teacher can use scriptwriter interface (Figure 3) to write plots and set up the digital scenarios (*e.g.,* background, foreground, masks, and props) and programs the robots' role (*i.e*., actions, facial emotions, and sound effects) on each stage of the journey based on the designed script.

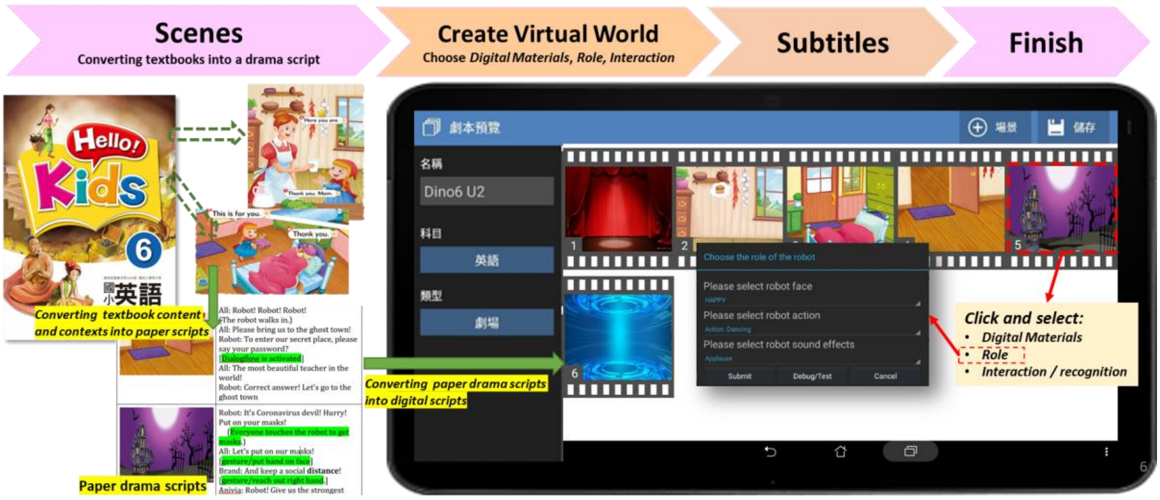

Figure 3. Scriptwriter Interface of the Main Control Module.

3.2 *Teaching Procedure of DSLE with Robot Actor*

At first, the teacher taught the students the content of the English textbook and explained the meaning of each sentence. Next, a description of the DSLE with the robot actor was presented, including the explanation of the drama script and demonstration. The teacher then provided students with instructions regarding the drama script, assisted them to practice the script (*e.g.,* moves or acts), and helped them to learn pronunciation. Afterwards, students are divided in small groups (5 to 7 each) to rehearsal using the system in turn. In addition, they might practice performing with a paper drama script after class. Following the rehearsals, actor groups performed a formal drama show using the system. The other classmates watching the show as an audience could reflect and learn from the actors. As each actor group had finished its performance, the teacher discussed the performance and let other classmates give advice to the actors. Finally, the drama performance videos were uploaded to the database for evaluation and reflection after class.

3.3 *Interaction Design*

Utilizing the physical interface of the robot, cognitive services, and DSLE, several modes of embodied interaction can be created. The interaction modes were integrated into a particular stage of the journey based on the drama script. It consists of context-related oral interaction with the robot, robot physical touch interaction, and gesture interaction. The teacher can insert some important learning materials into the learning drama script as a challenge from the robot that acts as a threshold guardian for student actors to get information, virtual objects, or pass a gate to the next journey stage. The robot actor will always give a command and instruction until actors can accomplish the challenge. Real-time mirrored feedback from the virtual world, and instant feedback from the robot are employed, so that the actors can get a real-time evaluation and remedial action during drama performance. The evaluation and real-time assessment will enforce students to learn the drama script in advance so that they can perform well in the learning drama with the robot actor.

The system will recognize actors' interactions and give real-time evaluation. When the system verifies that the actor has properly done his task based on the learning materials, the robot will show positive feedback (*e.g.*, happiness, smile, and joy), and the virtual world will also give a score to them and attach a virtual object or flow to next stage of the journey. On the other hand, if the actor makes a mistake during the recognition period, the robot will show negative feedback (*e.g.*, sadness, cry, and anger) and encourage them to try again. In such a situation, the virtual world will decrease the score and attach a burned face mask effect to actors. Example of the recognition process is shown in Figure 4.

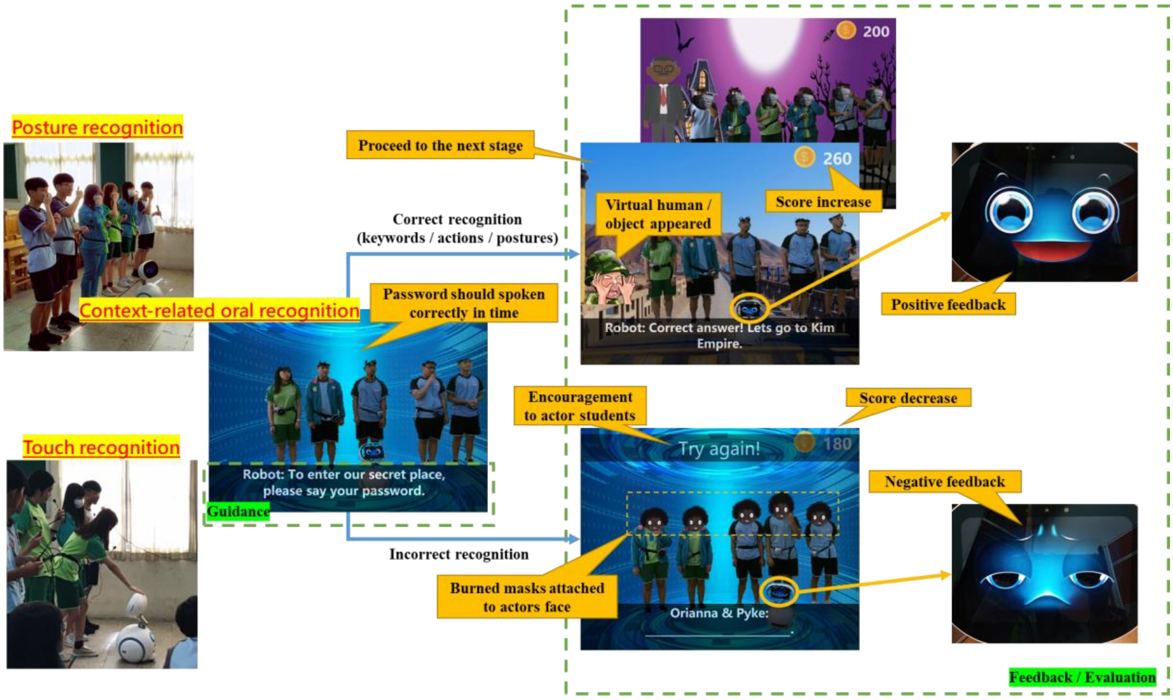

Figure 4. Example of the Recognition Process.

4. Experiment

4.1 Participants & Learning Materials

In a junior high school English as a second language course in Taiwan, this experiment was conducted. There were three classes randomly selected to become the experimental group A, experimental group B, and control group, respectively. All of the students in groups were grade 9 (around 15 years old) and taught by the same teacher. Experimental group A containing 39 students (25 males, 14 females) used the DSLE with robot embodied interactive modes, in which robot and student actors were immersed into a digital scenario and have physical robot touch interaction, gesture interaction, and context-related oral interaction. The experimental group B consisting of 31 students (18 males, 13 females) used the conventional DSLE, in which robot and student actors were only immersed into a digital scenario and had no recognition. In other words, in experimental group B, students only did drama performance with less interactions of robot actor (*i.e.*, the robot actor only spoke the subtitles based on context-related same as student actors did). The other class with 31 students (20 males, 11 females) was selected as the control group learned with conventional robot instruction approach, in which students used the display screen as social robots had in general and were not immersed into a digital scenario. Details of the experimental group A, experimental group B, and control group, with decreasing levels of interaction and immersion, respectively, are shown in Table 1.

Table 1. *How Students and Robots were Interacting with Each Other in Each Group*

Group	Immerse	Touch recognition	Gesture recognition	Context-related oral recognition
Experimental group A	✓	✓	✓	✓
Experimental group B	✓	×	×	×
Control group	×	×	×	×

This study compiled the materials taken from the English course textbook into a drama script. The drama script was developed by a school teacher with considerable experience in teaching English (more than 10 years). Additionally, the drama script screenwriting was based on the journey structure proposed by Vogler (2007) and Barab *et al.* (2010) to make the developed drama script convey the narrative structures and character development. All three groups used the same drama script.

4.2 Evaluation

This study was conducted for one month. A pre-test for total score ranged from 0 to 100 points developed by the teacher was administrated at the beginning of the experiment to evaluate the prior knowledge level of students. In order to keep the test results consistent, a post-test similar to but different from the pre-test was conducted at the end to examine students' learning outcomes. Based on the aforementioned teaching procedure and experiment subjects, the experimental design was developed, as shown in Figure 5.

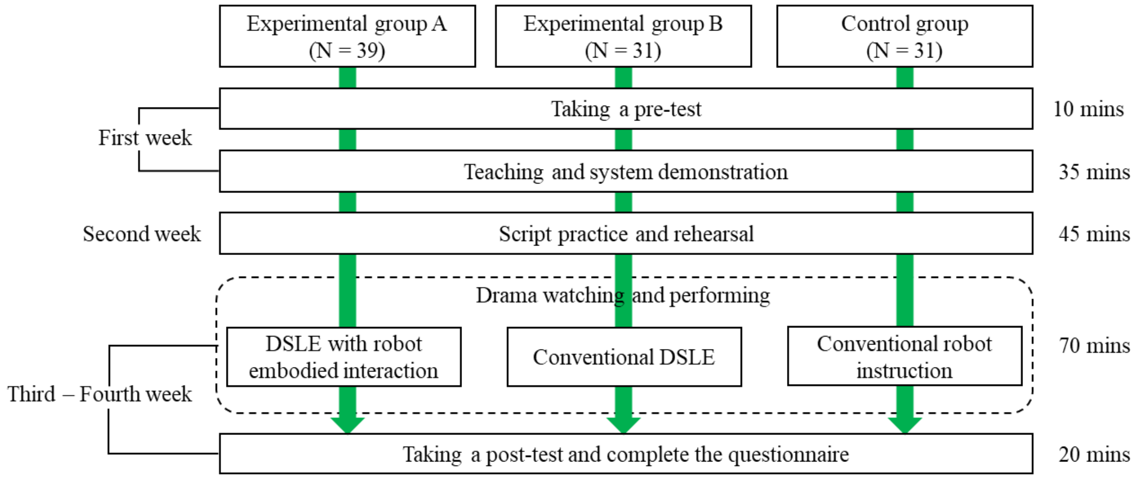

Figure 5. Experimental Design.

Based on the test scores obtained in this study, a single factor covariate analysis (ANCOVA) was used to compare the learning performance between the three groups. Additionally, a questionnaire with a five-point *Likert* scale was employed to examine students' learning motivation and engagement. The questionnaire that was used to evaluate the students learning motivation after the treatment was developed based on Hwang, Yang, and Wang (2013). It consists of 7 items questions (*e.g.*, "I will practice the script seriously when participating in the scenario of the script with the robot together in a drama journey") with the *Cronbach alpha* value proposed by the original study was 0.79 (N = 56). While for evaluating the learning engagement, the emotional engagement measure of Jamaludin and Osman (2014) was adopted. It consists of 5 items (*e.g.*, "Interacting with the robot in a drama journey can deepen my impression of the learning content") and has been reported a reliability coefficient (*Cronbach alpha*) of 0.955 (N = 24). Since the Taiwanese students had a low proficiency level, all items were translated to Mandarin.

5. Results and Discussion

5.1 Learning Performance Analysis

The ANOVA test was conducted before ANCOVA to verify whether the groups had similar prior knowledge. ANOVA test result (F = .367 with p > .05) indicated that there was no significant difference in the pre-test, suggesting that all three groups possessed the same prior knowledge before the experiment. Then, the ANCOVA analysis was performed using the pre-test scores as covariance and the post-test scores as the dependent variable.

The result of ANCOVA shows that the adjusted mean of the experimental group A, experimental group B, and the control group were 79.54, 64.45, and 72.51, respectively. Once the pre-test impact was removed, a significant difference emerged between the three groups with $F = 11.58$ ($p < .05$), demonstrating that significant differences in post-test scores were found between the three groups. By applying pairwise comparisons, it was found that experimental group A led both experimental group B and control group, demonstrating that the group of DSLE with robot embodied interactive modes had significantly higher learning outcomes than the conventional DSLE modes and the conventional robot instruction modes.

Students can learn better when the embodied interactive modes (*i.e.*, context-related oral interaction, gesture interaction, and physical touch interaction) are added into the robot actor and DSLE. Due to the interactive and instant feedback assessment provided by the virtual world and a robot with embodied interactions, students learn the drama script seriously to perform well in the drama journey, so they outperform those in the other group in terms of learning performance. As stated by Kerawalla *et al.* (2006), real-time evaluation and corrections during learning activities are essential. Thus, we concluded that more recognition and interaction in the situational learning environment could encourage students to study in advance.

Unexpectedly, pairwise comparison results also demonstrate that the conventional robot instruction group outperformed the conventional DSLE group in terms of learning outcomes. Possibly, this finding was caused by the students in the conventional DSLE group not participating in the direct interaction with the robot actor, but instead interacting with the virtual robot actor through the computer screen. Even though the conventional robot instruction group students were not immersed in the digital scenarios, they directly interact with the tangible robot actor. Based on previously published studies (Belpaeme *et al.,* 2018; Chang, Lee, Wang, & Chen, 2010; Leyzberg *et al.,* 2012), physical robots are more effective at fostering learning gains than virtual robots. In line with that, Ahtinen & Kaipainen (2020) stated that having robots physically present in a classroom contributes immensely to classroom interaction and learning.

5.2 Questionnaire Analysis

Questionnaire responses were analyzed with ANOVA to compare the students' learning motivation and engagement after received the different approaches. The questionnaire contained 101 responses, and 100 of them were considered valid copies. The ANOVA result of students' learning motivation shows that experimental group A scored 4.05, experimental group B scored 3.33, and the control group scored 2.97. Moreover, significant differences $F = 23.92$ ($p < .05$) were found among the three groups regarding learning motivation. Pairwise comparison showed that experimental group A was superior to experimental group B and the control group, implying that the learning motivation is higher for the DSLE with robot embodied interactive modes compared to the other two groups. It is suggested that robot-based learning systems that combine physically embodied robots with instructional tools or attractive multimedia objects inside the classroom can provoke a strong motivation to learn (Chang, Lee, Chao, Wang, & Chen, 2010; Chin, Hong, & Chen, 2014).

Moreover, it was also found that both of the DSLE with embodied and non-embodied interactive modes of robot actor could significantly improve the students' learning motivation in comparison with the conventional robot instruction mode. As claimed by previous studies (Liu *et al.*, 2017; Wu *et al.*, 2015), we believe that the DSLE can help to increase the novelty effect and interaction in situational learning so that the students can keep their learning motivation and fondness.

In terms of learning engagement, several previous studies (Fitter & Kuchenbecker, 2019; Verner *et al.*, 2016; Saerbeck *et al.*, 2010) claimed that robots are suggested to make interactions more fun and engaging. A mean score of 4.05 was obtained from the experimental data analysis in experimental group A, while 2.77 was achieved in experimental group B, and 2.90 was obtained in the control group. Based on the obtained F-value ($F = 22.61$ with $p < .05$), significant differences existed between the learning engagement of the three groups.

Pairwise comparisons revealed that experimental group A outperformed experimental group B and control group. However, no significant difference was found between the experimental group B and the control group. The ANOVA result indicates that the DSLE with robot embodied interaction group outperformed the other two groups in terms of learning engagement, while the learning engagement of the conventional DSLE and the conventional robot instruction group did not have a significant difference. This may happen due to the students in DSLE with robot embodied interaction group have to perform robot actor' challenges in order get information, virtual objects, or pass through a gate to the next journey stage, which will be fun and engaging for them. We conclude that the immediate feedback support that was imposed on the learning system led to increased engagement in learning (Yeh, Cheng, Chen, Liao, & Chan, 2019).

6. Conclusion

The work proposed a situational learning environment with a robot as a companion actor together with students role-playing in the journey inside the digital scenario. The robot actor was designed and programmed to do the same acts as human actors do in situational learning activities. Both robot and student actors are immersed into the digital scenarios, play drama, and have interactions with robot, scenarios, and virtual objects inside DSLE. The major role of the robot in the script is to play as a messenger to provide guidance, and at the same time as the threshold guardian, thus using the learning materials is necessary for students to complete a task and move to the next part of the drama journey. The robot with cloud AI capabilities and DSLE offers real-time feedback to evaluate whether students learn the knowledge.

Based on the experimental results, it is concluded that students can learn better when the embodied interactive modes (*i.e.*, context-related oral interaction, gesture interaction, and physical touch interaction) are added into the robot actor and DSLE. More interactions provided by the proposed system could enforce students to study in advance in order to perform well in the drama performance. Furthermore, our findings demonstrate that the robot embodied interactive modes can promote learning motivation and engagement of learning inside DSLE.

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