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My Classroom Robot: Exploring Telepresence for K-12 Education in a Virtual Environment

Elizabeth Cha, Jillian Greczek, Ao Song, and Maja J Matarić

***Abstract*— Telepresence robots have the potential to improve access to K-12 education. However, designing robots for classroom use presents unique challenges from both logistical and technological perspectives. To address these challenges, we created My Classroom Robot, an interactive game in which players can operate a virtual telepresence robot in a classroom environment. The virtual classroom environment allows us to collect data and prototype different designs prior to involving the high overhead required in going into the real classroom. In this work, we present the design of My Classroom Robot, an initial evaluation, and the lessons learned from its development.**

I. INTRODUCTION

Each year, more than 6.5 million children in the United States miss considerable amounts of school causing significant educational and social issues [1]. Telepresence robots have the potential to expand access to K-12 education and enhance the learning experience for students absent from the classroom [20], [25], [27]. Continued access to the school social learning environment also improves cognitive and social outcomes [5]; telepresence systems have already been shown in anecdotal deployments to be a powerful gateway for minimizing the effects of physical separation from the school environment [20].

However, most telepresence robots are designed for adult users and workplace environments, such as offices and hospitals [16], [25]. The classroom environment and young users present unique design challenges; the environment is diverse and highly dynamic and student users vary broadly in capability [24]. Hence, the school environment is a challenging area for new technology design [21].

Large scale in-school robot deployments and studies are very challenging for both roboticists and educators. Since telepresence robots are still a novel technology, it is as yet unknown how students will respond to their inclusion in the classroom [20]. Disruptions in the learning environment also negatively impact the operator and students' experiences, therefore hindering adoption.

To better understand potential challenges of telepresence inclusion in the classroom, we created an interactive game, My Classroom Robot, that simulates the operation of a telepresence robot in a virtual classroom. Virtual environments have been effectively used in research in various domains [18]; their main drawback is the lack of sensory feedback and realism of interacting in the real world. Telepresence, however, provides a unique research opportunity as operators encounter many of the same issues in the virtual environment, due to the lack of immersion and feedback [16]. Moreover, telepresence platforms are physically simple, having no manipulation capabilities, making their realization and operation in virtual environments more realistic.

Elizabeth Cha, Jillian Greczek, Ao Song, and Maja J Matarić are with the Interaction Lab, Department of Computer Science, University of Southern California, Los Angeles, CA 90089, USA {echa,greczek,aosong,mataric}@usc.edu

Fig. 1. *My Classroom Robot* is an interactive tool that allows players to operate a telepresence robot in a virtual classroom.

The aim of My Classroom Robot is to explore important research problems in designing telepresence robots for K-12 education. A virtual classroom environment allows researchers to more easily test new features and designs with a large number of students. For schools that plan to introduce a telepresence robot, the game can familiarize students to both the robot and the notion of a remote telepresence-embodied student, facilitating acceptance.

We discuss the design considerations and implementation of the game. We then present an initial evaluation of the game with 95 middle school students. Last, we discuss some of the lessons learned and how they may impact the future development of virtual technologies for human-robot interaction (HRI) research and for in-classroom deployment.

II. BACKGROUND

Telepresence robots that combine mobility and videoconferencing capabilities are a recent development that focus on providing the operator with an embodied presence in the remote environment [16], [24]. A main benefit of these platforms is enhanced independence, as the operator is able to freely move about the environment and a greater feeling of presence through active engagement with people in the remote environment [16].

Telepresence systems to date have been primarily utilized in workplaces, such as offices and hospitals, to support telecommuting [17]. More recently, there has been interest in using such robots to improve access to K-12 education;

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the educational environment, however, presents unique challenges as classrooms are cluttered and dynamic and users range in age. There are also social and privacy concerns that arise from telepresence usage in a classroom of children. Furthermore, remote students may attract greater attention or even bullying due to the robot embodiment [9], [20].

Deployments of telepresence robots in the classroom to date have shown significant potential to minimize the effects of separation from the classroom [20]. Due to the many challenges, these past works have primarily utilized small scale deployments with mostly anecdotal results [6], [9], [20], [27], [28]. Therefore, much more research is needed to understand and address the challenges of telepresence for K-12 in-school use.

Due to the high overhead and concerns with in-classroom deployment, we explore the use of a virtual robot and classroom. Virtual environments are often used in research to simulate aspects of the real world [8], [18]. Since researchers can shape both the environment and its virtual inhabitants, they are also able to create a more uniform and controlled experience for participants [18], enabling researchers to explore problems that may not otherwise be feasible [10].

In the HRI context, virtual environments have been used to train robot operators, evaluate robot control methods, and get user feedback on robot behaviors [4], [14]. These environments enable researchers to test different approaches without real-world outcomes [14], whichis beneficial for applications where real-world testing is difficult or dangerous [3], [14].

Virtual environments also enable larger-scale and geographically broader data collections and experiments [2], [7], [26]. Accessibility is especially important for HRI, as people's actions, responses, and behaviors can vary greatly based on culture, age, and experiences [2], [7].

Unavoidable limitations in realism are the main drawback of virtual environments. While certain physical features are readily simulated, incorporating real-world human interaction dynamics is very challenging. Since many of the research questions we seek to investigate focus on the operator, the virtual environment offers many benefits, including the ability to quickly prototype and test new system designs and features. As most platforms are designed for and by adult users, greater inclusion of feedback from child operators is needed. Using a game context also increases engagement and motivates students [13], [19].

III. Design Considerations

The primary goal of this work is to design a tool that enables exploration of telepresence robots as tools for providing continued access to K-12 education. Since the classroom is a sensitive environment, we hesitate to deploy a new technology without a better understanding of how it will affect the dynamics of the classroom. Hence, we consider user needs, how the robot might function in the classroom, and potential shortcomings when designing My Classroom Robot. Drawing from prior work and focus groups with teachers, we identified the following areas of concern.

1) Interface: Prior work has shown the importance of a telepresence robot interface to the operator's experience [16]. In the classroom, this can negatively affect users' ability to engage in activities. Integrating new features and testing different designs is a time consuming and costly process. Thus, My Classroom Robot should enable researchers to narrow the design space by prototyping and evaluating different designs without the overhead of a true deployment.

2) Feedback: Current telepresence robots are typically designed to be controlled from a personal computer. That interface limits the operators perceptual feedback to the operator, causing unintended violations of social conventions, such as using poor voice volume control or physical robot positioning [16]. Providing other types of feedback helps to minimize these issues and enable greater engagement. Adding visual feedback of the remote emobidment can improve awareness of the robot's appearance and behavior [23]. A private chat interface could also allow teachers to discretely inform the students when they are acting inappropriate.

3) Autonomy and Navigation: Challenges with navigating telepresence robots are well established [16], [24]. At the lowest level, the operator directly controls the robot, providing commands that map to the robot's movement. The operator's ability is often influenced by the available input devices (e.g., joystick, keyboard). Some level of autonomy can enable operators to focus on the classroom, but the need for navigation may be limited due to the classroom's clutter, the robot's non-adjustable height, and fixed school schedule.

4) Expressiveness: Affordable telepresence robots are simple in their physical design: they consist of a visual display mounted on a mobile base, about human height, with some sensors. The lack of arms and the inability to move the robot's display independently from the body makes it difficult for users to utilize natural nonverbal communication. Nonverbal signals represents a significant portion of human communication and facilitate information exchange as well as coordination. Moreover, functional signals, such as hand raising and pointing, are important for active participation. This indicates the need for the exploration of new communication modalities that make up for these limitations.

5) Inclusion: Inclusion of remote users in group activities is challenging due to the robot's lack of manipulation capabilities. Interactive learning activities, such as hands-on science experiments, engage students but are challenging to adapt to remote students' capabilities. Other approaches, such as performing the activity at home, can facilitate participation and enhance inclusion.

6) Authority: In classrooms, teachers have authority over students' time and activities and must discipline students who violate classroom rules. The inclusion of a telepresence robot presents an interesting dilemma: the robot is designed to provide the operator with greater independence, but what control should the teacher have over the robot's actions? The research question of how the teacher's authority should affect the design and implementation of the telepresence system must be considered for future in-classroom deployments.

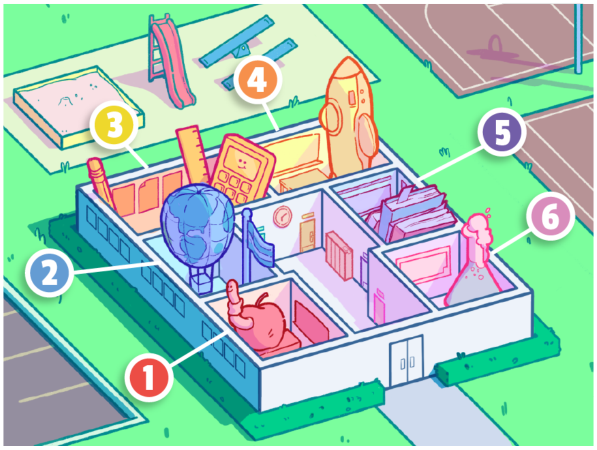

Fig. 2. Players can select a mission from the map of the school; each mission takes places in a different classroom with a scenario that matches the class subject shown on the map.

IV. GAME DESIGN AND IMPLEMENTATION

The main goal of My Classroom Robot is to better understand the challenges of telepresence robots for K-12 education. However, we also aimed to make the game a viable tool for facilitating acceptance and improving inclusion of remote students. We present the game design and discuss how it relates to these goals and design considerations.

A. Overview

My Classroom Robot is a first player game in which the player controls a telepresence robot in a virtual environment that models a school. The player is told that s/he is controlling the main character, the robot, in order to complete a "school day." The game is divided into different levels or missions, each focusing on a specific research problem. The first iteration of the game has six missions that take place during different class periods. We designed the game to be easily customizable, so as to accurately represent the player's specific school environment.

After the start screen, the player inputs her/his name as the robot's to emphasize that the robot is acting as the player's embodiment, not as a separate character. The player is then taken to the mission select screen in the form of a school map, where each classroom is a different game level.

Initially, only the tutorial mission is available while the others are "locked" (indicated by a lock icon) until the tutorial mission is completed. Since the current design utilizes one mission per research question, there is no subsequent level order but this can be adapted if missions become interdependent.

The game level interface mimics the interface of the Suitable Beam+ robot, with additional features for game play. Each mission has objectives the player must successfully complete and is scored based on the players completion time. The game progress is shown at the top of the screen.

B. Visual Style

Since mimicking the complex visuals of a real classroom is complex and costly, we chose not to make the virtual environment photorealistic and used a cartoon-like rendering style instead, thereby also avoiding issues of the Uncanny Valley [22]. Since we still aimed to give players a real-world experience, we designed the virtual classrooms to be reasonably accurate in content and dimensions. However, we also limited the amount of clutter in the classroom and the complexity of the 3D models to allow the game to be accessible to players on devices with limited processing power and graphics capabilities.

C. Robot

The robot in the game is modeled after the Suitable Beam+, a low cost telepresence robot. It is 52.9 inches tall and contains a 10.1 inch display that continuously shows the operator. We chose this robot for its size, cost-effectiveness, and ease of use which make it feasible for in-school use.

The robot has two cameras that provide wide angle views of the remote environment. The front facing camera is on the robot's display and is positioned for communication with people in the remote environment. The second camera is under the display, pointing downward, and shows the robot's "walking area" to help the player to navigate he robot. The virtual robot also has a light ring located below the display that provides an additional nonverbal communication channel to signal various visual cues.

D. Game Level Interface

After choosing a mission, the player is taken to the game-level interface. Since all telepresence robots utilize at least one camera to show the environment around them, the game can be adapted to fit a specific platform by altering the size and position of the game elements or removing them.

The interface shows forward- and downward-facing camera views along with game play buttons and information. The player moves about the environment by clicking and holding in the lower camera view. A silver arrow shows the path of the robot's movement; an adjustable speed slider is located below the camera view.

The objectives for each mission are shown in the top left panel. Once an objective is completed, a check mark appears next to it. Examples of objectives in the tutorial include navigating around the room and talking to the teacher.

The top right panel shows a 3D model of the robot to provide players visual feedback of the robot's appearance and actions (e.g., movements and light signals). This is meant to increase the player's awareness of how the robot is perceived by people in the remote environment.

The bottom left panel contains information and buttons related to game play. This is the primary method of communication for the player. The bottom right panel shows light signals the player creates as well four buttons that facilitate game play: zoom in, zoom out, go to the light signal design screen, and interact with objecs in the environment.

E. Light Signal Design Screen

An important research question for remote presence usability in general is how to facilitate nonverbal signaling. We investigate this problem through the use of a light ring. We

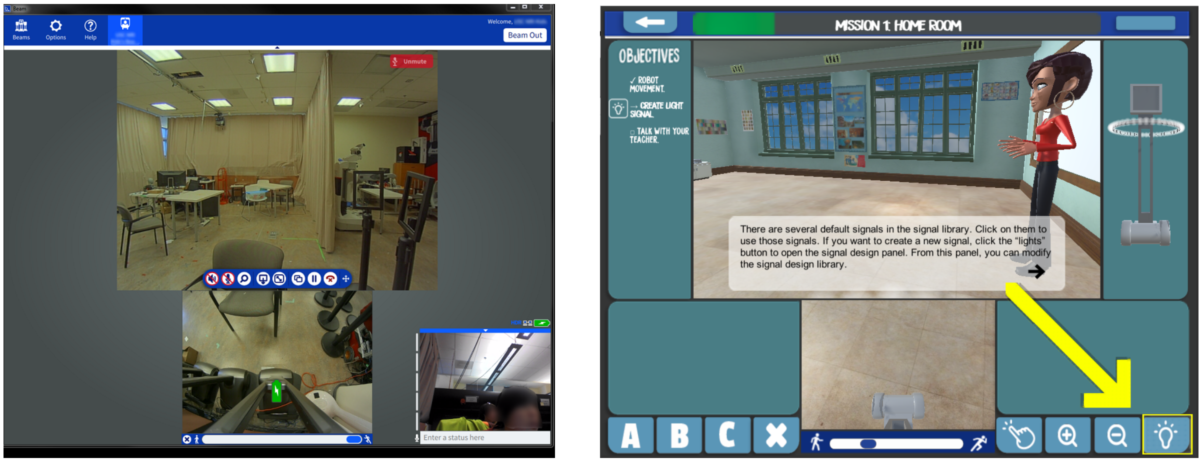

Fig. 3. The interface and robot are modeled after the Suitable Beam+. The interface has the same layout and camera views as the Beam+, but contains additional options for game play and the robot contains extra lights for signaling.

provide players with the functionalities to create light signals the robot can use to enable both functional and affective nonverbal signaling.

The light signal design screen is accessed via a light bulb button on the bottom right of the game level interface. The screen is titled "Light Signal Work Station"; it allows the player to choose the color, pattern, and frequency of the light signal. A preview is shown on both on and off the robot.

After finalizing the choices, the player presses the plus button, names the new signal, and presses confirm to add the new signal to the library. The player can use the delete button to remove the last signal added to the library.

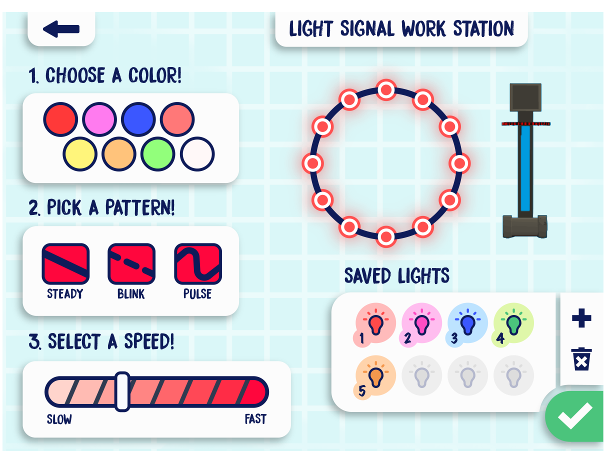

Fig. 4. The light signal design screen is used to create signals for the robot's light ring.

F. Missions

The game contains six missions, each of which with a subject related to the mission objectives and the corresponding school room the robot moves in. Once the objectives for a mission are completed, a "Congratulations" box gives the user a mission-specific ribbon and score.

1) Mission 1: Homeroom: The first mission is set in homeroom and is a tutorial to learn how to operate the robot and become familiar with the game interface. The tutorial can also be used to test various training strategies.

The homeroom mission has three objectives. The player is prompted to complete each objective by the dialog that appears on the screen. For each objective, the relevant areas of the screen and controls are highlighted and described. The first objective is to move about the empty classroom. The second objective is to create a light signal. The final objective is to interact with the teacher.

2) Mission 2: Social Studies: The second mission is set in a social studies class and explores issues related to navigation of the robot in the remote environment. Prior work has identified navigation as a key challenge for the usability and adoption of telepresence robots [16]. Classroom environments are even more challenging than the typically studied work environments, as they are crowded, cluttered, and highly dynamic. Students are also restricted in their movements during portions of the class period. Hence, the amount of navigation in class may vary by the subject, activity, and teacher.

The social studies mission goal is to assess the player's ability to accurately drive the robot around the classroom. The player is told to drive over to join a group and answer several geography questions. The answers are found in maps on the classroom walls; the player must navigate to the maps and loop up the answers.

3) Mission 3: Math: The third mission is set in a math classroom and explores functional signaling using the robot's lights. In physical classrooms, nonverbal signals are commonly used to avoid disrupting the class with talking. Therefore, the objectives of this mission are to create common nonverbal signals: "raise your hand," agree, and disagree. We limited the scope of each mission to these signals to ensure the game is playable in one session. The last objective is to answer the teacher's questions using the new signals.

4) Mission 4: Physics: The fourth mission is set in a physics class and focuses on pointing gestures. Deictic gestures enable the robot operator to indicate a choice, draw attention, or clarify information. In this mission, the player works with a team to build small bridges using the provided pieces within certain length and weight constraints. Each team member takes turns in adding pieces to the bridge. When it is the player's turn, they are given a choice of three pieces. To complete the first three objectives, the player creates light signals to indicate pointing left, right, and forward to select the desired piece. The remaining three objectives consist of completing three bridges by using the created signals to indicate the player's building piece choice.

5) Mission 5: English: The fifth mission is set in an English class and explores affective signaling. In human communication, affect is conveyed through a variety of channels including body language, paralinguistic cues, and facial expressions. As telepresence displays only show the operator's face, many aspects of body language are lost. While voice and audio can be very expressive, they also require high bandwidth, quality equipment, and appropriate conditions. Hence, it can be difficult for people around the robot to accurately estimate the emotional state of the telepresence operator and respond properly and inclusively.

The context of this mission involves the player listening to stories told by classmates and using affective light signals to react to what it has heard through the robot. The mission contains five objectives; each consists of the player hearing a story from a classmate and signaling to the class how s/he felt about the story. The player is asked to create and define a light signal s/he feels is appropriate and reflects his/her feelings about the story.

6) Mission 6: Chemistry: The sixth mission is set in a chemistry class and focuses on collaboration. One of the major research questions relating to telepresence in K-12 classrooms is how the remote student can more actively engage in the class activities. Better inclusion also helps classmates to feel that the student is present and relieves the remote users negative emotions associated with isolation. Hence, our aim is to explore how a remote presence robot can play a role in regular learning activities with its limited physical capabilities.

This is especially relevant in collaborative learning scenarios, where students work together to share ideas [12]. Working in groups often occurs in classes featuring hands-on experiments, typically in science. Hence, we chose to investigate collaboration in the context of a chemistry class, with the player working in a group to perform experiments.

This mission contains five objectives. The first requires the player to join an laboratory group. The remaining objectives require the group to perform pH tests to answer a set of chemistry questions. The game play is designed to encourage the player to actively participate by going to read the results of the pH test strips.

G. Implementation

The game was implemented in the Unity3D Game Engine which contains many game-oriented libraries and provides convenient methods for creating user interfaces. Unity3D also provides broad cross-platform compatibility, making it easy to port the game to different platforms.

V. EVALUATION

We conducted an initial play test of the game to evaluate its design, observe reactions, and identify issues that should be addressed as we anticipate changes are needed in both design and implementation to create an effective research tool. We did not focus on any of the mission's research questions as each requires its own study to properly evaluate.

A. Participants

The play test took place at a K-8 school in the Los Angeles area and included 95 (48 male, 47 female) participants ranging from 11 to 14 years of age ($M = 12, SD = 0.64$). Students were drawn from three classes, including a 7th grade science class, a 7th grade math class, and an 8th grade museum science class.

We administered a short survey asking about participants' technology use at home. 91% of students reported having at least one game console (e.g., X-box) in the home and 76% of students reported owning a tablet. 84% of students reported playing computer games at home with 60% of students classifying their usage as regular or frequent. Only 55% of students reported ever using any sort of video chat program or application while 22% classified their usage as regular or frequent.

B. Procedure

Participants were located in their respective classrooms and sat at tables of 2 to 4 students. The experimenters first introduced themselves and told participants the game would help researchers to design robots that can function better in the classroom. Earlier in the week, the teacher had already provided a short introduction about the general notion of the robot and how it would be used. None of the students had seen pictures of the robot or the platform in person.

After introductions, participants were given a brief overview of the game as well a short demonstration on how to play the game by one of the experimenters. Participants were then instructed to fill out a survey with some demographic information and about their technology usage and experience. After they finished, they raised their hand and an experimenter brought them an iPad and helped them to start the game.

Participants were given about 25 minutes to play the game. During that time, they were allowed to talk with other participants and discuss the game. Four experimenters were present in the room at all times to provide assistance to participants with technical issues in the game or questions about game play. The experimenters also walked around the room listening to students comments and talking with them about their experiences with the game. After the game play period ended, participants were instructed to finish the level they were on and close the game. The teacher then asked the students their thoughts about the game.

C. Results

Since this was a preliminary play test evaluating the design and implementation of the system, we present qualitative observations about both.

1) Attitudes: The overall reactions from participants to both the game and idea of the robot were positive with many students describing them "fun" and "cool." Many students also expressed enthusiasm about the prospect of a real-life robot being used in their classroom and asked about when it might arrive.

One concern was the effect of participants' experiences on their attitudes towards both robots and telepresence technologies. Since none of the participants or their teachers had ever seen or interacted with a telepresence robot in real life, a novelty effect may exist for both the virtual and real-life robot. After interacting regularly with either platform, users' attitudes may shift to be less excited or forgiving [11].

The participating school does not currently have any classes or after school activities related to robotics, but will be starting a club in the coming academic year. Since students recently signed up for this club, teachers commented that their excitement about robots was particularly high at the time the play test occurred.

2) Technical Issues: Several participants experienced technical issues that negatively impacted game play. All of these participants continued or attempted to continue playing the game throughout the remaining play test period. However, several students complained and expressed some frustration when asking an experimenter for assistance. Post survey comments included that the game "had issues" or "made them redo things." Since participants played for a relatively short time, this was not a significant issue, but technical issues with the game will be fixed so as to extend the game's play time in future uses.

3) Interface: Most participants were able to understand the game level interface from the short demonstration and the tutorial mission. Some of the more common questions centered around the light design screen. Since designing abstract light signals is a new experience, several students expressed some confusion about the general concept. This was enhanced in situations where they needed to simultaneously create and utilize a light signal, especially as the instructions were found to be vague. Several students still expressed that it was one of the funner parts of the game.

4) Platform Control: Several participants had trouble navigating around the environment. This was particularly challenging in Mission 6, when participants needed to move the robot to very precise locations to read the results of pH test strips. The robot often got stuck after being driven into furniture, such as the tables containing the pH experiment. This was exacerbated by limitations in the robots driving interface and narrow views. While the Beam+ interface allows the robot to easily turn in place and drive in reverse, these functionalities are still limited in the current implementation of the game. The majority of students reported these issues as the greatest challenge when playing the game. Since these features were cited to be crucial in navigating small and constrained spaces, we plan to improve this aspects of the robot's control interface. This will also make the virtual experience more consistent with the physical robot system.

5) Virtual Behavior: We observed that participants did not treat the environment, including the virtual students, as they would in the real classroom. Players regularly bumped the robot into furniture and the virtual people without concern. We believe this is due to poor feedback from the system and the difficulty players faced in situating themselves in the remote environment. Several participants commented that it was difficult to see the surroundings. This was also supported by many players who became stuck in Mission 6 but did not realize what had happened.

VI. DISCUSSION

While the initial deployment and evaluation of My Classroom Robot offers some promising insights into our research domain, there is still much work needed to make the game an effective research tool. Since there is relatively little prior work in this area, we believe My Classroom Robot can help researchers go from the lab to the classroom more effectively. In this section, we discuss our experiences, their implications, and key lessons learned.

A. Authenticity of the System

In the initial evaluation of My Classroom Robot, we found several differences between controlling a telepresence robot in the game environment and in the physical world. As with all virtual systems, it was difficult to create a truly immersive environment, but we theorized this to be less of an issue in our game, as operators of telepresence systems naturally encounter many of the same problems, such as the lack of sensory feedback. Our results showed that players did not treat the robot or remote environment as they would a real classroom environment.

Since the game view was more narrow and zoomed in than the view of a physical robot, participants had difficulty envisioning the surrounding environment. Consequently, in close proximity to objects and people, they often collided or became stuck. Lack of familiarity may also have exacerbated this problem as users did not have a good sense of the room as a whole. These issues can hopefully be addressed with the use of a wider angle view for greater visibility and familiarizing users with the entire environment [15].

Another issue we found was the lack of realistic feedback to the player, as the virtual environment had simple dynamics compared to the physical word. For example, when the robot collided with someone, the virtual characters did not visibly react. By implementing more realistic behavior, the system will more closely mimic the real world. The game can also provide more instructions as well as feedback according to the appropriateness of the players behavior.

The choice of play-test platform, the Apple iPad Mini, also contributed to these challenges. We initially chose to simplify the system to make the game accessible across a wider range of devices. However, the small size, lag, and weaker processor imposed game play limitations. In the future, we plan to use a more powerful computing platform to avoid these issues and more closely mimic a real system.

B. Signaling

We also plan to redesign the tutorial and description of the light signaling system as many students expressed some confusion over the general concept of light signals. The use of light to signal affective information is new, so students may require greater support and training to use it.

C. Training and Expectations

By overcoming the gap in authenticity, the system can be used as a training tool to teach the operator how to control the robot. Interactions, however, are more difficult to simulate due to human unpredictability. We also hope that the system can be used to provide students in the remote environment with a better understanding of the physical platform. This with help with setting expectations and more readily perceiving and accepting the robot as the remote embodiment of the operator [20].

VII. Conclusion

In this work, we presented My Classroom Robot, an interactive game designed to facilitate research in telepresence for improving access to K-12 education. Our motivation is to assist researchers in gathering preliminary data to narrow the space of solutions before going into real world classrooms. As many of the targeted research problems have little prior work, this reduces the time, cost, and effort needed from researchers. It also enables data collection from a larger set of users than is feasible on a robot in real world classrooms where such data collection is disruptive to schoolwork. We presented several research problems we hope the game will assist in exploring.

We detailed the design and creation of the game and presented a preliminary evaluation of the system through a short play test by 95 middle school students. We found that the novelty of the robot (both the virtual and real-world platform) created high enthusiasm for the game. However, we also found several technical issues that hindered game play that we plan to resolve in order to expand the usefulness of the game as a research tool.

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