Everybody Needs Some Body to Teach: Embodiment, Telecommunication and Telepresence in STEM Learning

Mr. Glen Hordemann, Texas A & M University

Glen Hordemann is a Computer Science PhD student at Texas A&M University. He is part of the Embodied Interaction Lab (TEILab) and The Institute of Technology-Infused Learning (TITIL). His current research focuses on telepresence robots and AR/VR enhancements to improve the embodiment of remote users. He has a B.S. in Computer Science from Gonzaga University and an M.S. in Computer Science from Bowling Green State University. His research interests also include AI and High Performance Computing.

Dr. Malini Natarajarathinam, Texas A&M University

Dr. Malini Natarajarathinam joined the faculty of Industrial Distribution Program at Texas A&M University in 2007. Natarajarathinam received her Ph.D. in Supply Chain Management from The University of Alabama. She received her Bachelor of Engineering (Major: Industrial and Systems Engineering) from Anna University [Tamilnadu, India], her MS in Industrial Engineering from Auburn University, her MA in Management Science and MS in Applied Statistics from The University of Alabama. She has experience working with many industries such as automotive, chemical distribution etc. on transportation and operations management projects. She works extensively with food banks and food pantries on supply chain management and logistics focused initiatives. Her graduate and undergraduate students are integral part of her service-learning based logistics classes.

She teaches courses in strategic relationships among industrial distributors and distribution logistics. Her recent research focuses on engineering education and learning sciences with a focus on how to engage students better to prepare their minds for the future. Her other research interests include empirical studies to assess impact of good supply chain practices such as coordinated decision making in stochastic supply chains, handling supply chains during times of crisis and optimizing global supply chains on the financial health of a company. She has published her research in Journal of Business Logistics, International Journal of Physical Distribution and Logistics Management and peer-reviewed proceedings of the American Society for Engineering Education.

Dr. Sharon Lynn Chu, University of Florida

Dr. Chu received her B.Soc.Sci (1st Class Honors) in Communication and New Media from the National University of Singapore, her MS in Computer Science and Applications and a graduate certifcate in Human-Computer Interaction from Virginia Tech, and her Ph.D in Human-Computer Interaction from Texas A&M University. She is the Director of the Embodied Learning and Experience Lab at the University of Florida. The ELX Lab conducts research in two main areas: cyberlearning and positive computing.

Dr. Mathew Kuttolamadom, Texas A&M University

Dr. Mathew Kuttolamadom is an associate professor in the Department of Engineering Technology & Industrial Distribution and the Department of Materials Science & Engineering at Texas A&M University. He received his Ph.D. in Materials Science & Engineering from Clemson University's Int'l Center for Automotive Research. His professional experience is in the automotive industry including at the Ford Motor Company. At TAMU, he teaches Mechanics, Manufacturing and Mechanical Design to his students. His research thrusts include bioinspired functionally-graded composites, additive/subtractive manufacturing processes, laser surface texturing, tribology, visuo-haptic VR/AR interfaces and engineering education.

Prof. Francis Quek, Virginia Polytechnic Institute and State University

Francis Quek is a Professor at Texas A&M University (Visualization, and Computer Science and Engineering and Psychology - by courtesy). He joined Texas A&M University as an interdisciplinary President's Signature Hire to bridge disparities in STEM. Formerly he has been the Director of the Center for

Human-Computer Interaction at Virginia Tech. Francis received both his B.S.E. summa cum laude (1984) and M.S.E. (1984) in electrical engineering from the University of Michigan. He completed his Ph.D. in Computer Science at the same university in 1990. Francis is a member of the IEEE and ACM. He performs research in Human-Computer Interaction (HCI), learning sciences and technology, embodied interaction, embodied learning, HCI for accessibility (especially for individuals with blindness), multimodal verbal/non-verbal interaction, multimodal meeting analysis, vision-based interaction, multimedia databases, medical imaging, assistive technology for the blind, human computer interaction, computer vision, and computer graphics. http://teilab.tamu.edu

Mr. Osazuwa John Okundaye Jr, Texas A&M University

Osazuwa is a third year PhD student at Texas A&M University. He is a part of the Texas A&M Embodied Interaction Lab (TEILab). His research is motivated by the idea of an embodied conception of the mind. He comes from an interdisciplinary background having earned a Bachelor's degree in psychology and a Masters of Science in Visualization afterward. He is versed in engaging the theoretical aspects of Human-Computer Interaction while able to engage in computer graphics applications (computer-aided design, modeling, animation, and 3D fabrication) and concepts pertaining to Computer Science.

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Abstract

This paper outlines a new project for providing STEM education to remotely situated students in the absence of local STEM expertise using telepresence, augmented reality, and virtual reality. It uses the context of rural school districts with a high concentration of minority students to provide real-world grounding for the research being conducted.

Rural and small towns lag behind the suburbs and cities in science education. In the National Assessment of Educational Progress, 12th graders scored 11 and 19 for town and rural students, while students from the city or the suburbs scored 29 and 41, respectively. This town and rural students account for over 20% of all US public schools. A critical reason for this is a lack of STEM teaching expertise. Only 47% of science teachers have a science or engineering degree.

STEM employment grew 24.4% over the last decade, compared to a 4% growth in other occupations. STEM workers earn 29% more than non-STEM workers. This trend holds despite educational level. Despite this, women make up only 25% of computer scientists and 14% of engineers. African-Americans and Hispanics make up 14% and 13%, respectively. A lack of quality education to prepare for STEM fields, a lack of encouragement to pursue STEM from an early age, being less likely to believe they can succeed in STEM, and a lack of role models are all reasons given for these numbers. Income also has a factor on willingness to believe in one's ability to succeed at STEM and likelihood to self-select into STEM. Students from low income families were more than twice as likely to elect not to enroll in science classes than students from high income families, and four times as likely to believe they are unlikely to complete a bachelor's degree.

These issues all demand STEM educators. However, there is a severe issue with the STEM educator pipeline. Just 0.17% of high school students with an interest in STEM who take the ACT plan to pursue an occupation or college major in science education.

This paper builds on a 3-year project that placed University-based students in a distance-teaching mode to support physically-predicated technical learning in a distal high school at the Texas-Mexico border. These university students fill in a key gap in these high schools as STEM mentors, role-models, and instructors. Our interventions took place at a school many hours distant from the supporting university students, which makes the use of remote technologies essential for providing STEM support. University students met with high school students through video

teleconference. We compared mentor representations and interactions with these models and compare them to the ”gold-standard” of co-present instruction.

This paper lays out the real-world context in which our research takes place, explaining the practical testing grounds for the research being conducted. It provides a solution to finding STEM experts to provide STEM expertise to isolated rural classrooms. A pilot study is explained and examined which highlights some of the difficulties of using a telepresence solution. The experiences and results of this study formed the basis for the research project. Finally, we detail the project and the initial phases of research. Our research focuses on how embodied communication, involving speech, gaze, and gesture, may be mediated through mobile telepresence technologies to support hands-on distance instruction. We will discuss some initial ideas for using augmented and virtual reality to bring elements of physically embodied interaction into the telepresence arena.

Key Words

STEM, Telepresence, Making, Embodiment, MentorCorps, Cyberlearning

Introduction

STEM employment grew 24.4% over the last decade, compared to a 4% growth in other occupations. STEM workers earn 29% more than non-STEM workers.[1] This trend holds despite educational level. As the market for STEM employees grows, today's students need to be prepared for the future job market in order to succeed at the high-paying STEM jobs.

American schools are one of the critical places where students might learn these skills, but in the cases of electronics, 3D design, programming, and similar Making technologies, many students and schools lack access to technologically oriented teachers, mentors, and role-models. Only 47% of science teachers have a science or engineering degree[2]. It is not a simple matter to merely hire more STEM-focused teachers. There is a severe issue with the STEM educator pipeline. Just 0.17% of high school students with an interest in STEM who take the ACT plan to pursue an occupation or college major in science education.[3]

This issue is exacerbated in rural areas, for women, and for minorities. Rural and small towns lag behind the suburbs and cities in science education. In the National Assessment of Educational Progress, 12th graders scored 11 and 19 for town and rural students, respectively, and 29 and 41 for city and suburb dwelling students[2]. African-Americans and Hispanics make up 14% and 13% of computer scientists and 14% of engineers, while women make up only 25% of computer scientists and 14% of engineers. A lack of quality education to prepare for STEM fields, a lack of encouragement to pursue STEM from an early age, being less likely to believe they can succeed in STEM, and a lack of role models are all reasons given for these numbers.[4] Income also has a factor on willingness to believe in one's ability to success at STEM and likelihood to self-select into STEM. Students from low income families were more than twice as likely to elect not to enroll in science classes than students from high income families, and four times as likely to believe they are unlikely to complete a bachelor's degree[5].

To address these critical issues, the project described in this paper will develop critical technologies, processes, and training programs where STEM university students act as remote STEM instructors and mentors to rural high school students. The hands-on nature of Making activities reduces the effectiveness of traditional screen-sharing and teleconferencing methodologies. This project will develop new technologies to embody these STEM mentors in the classroom to provide instruction that includes gesture, shared gaze, and speech interaction using telepresence robotics and augmented reality.

The major contributions of this project span across the fields of computer science, education, and psycholinguistics:

1. It examines the nexus of embodied communication of space, gaze, and body movement to support distance teaching and mentoring for hands-on STEM learning.
2. It studies how multi-channel communication can be engaged distally through a mobile telepresence robot enhanced with augmented and virtual reality that blends the project space of the student with the embodied space of the mentor.
3. It provides a real-world context for the research by combining science and technology research with the practical educational mission of rural technology education.

In this paper, we describe how this project will be implemented by describing critical aspects of the project and the research.

- We will discuss the real-world context in which we apply STEM teaching using Making as Micro-Manufacturing.
- We will outline our model for finding STEM experts in a cost-effective way with a STEM MentorCorps.
- We will review the data from our pilot study that formed the basis for this project, and examine lessons learned.
- We will detail the implementation and evaluation of our cyberlearning telepresence project, from an initial pilot study to a multi-year, multi-classroom program.

Making as Micro-Manufacturing

Using technology to provide an individual with some element of embodiment has numerous potential applications. Whether it is a land-based expert teaching enlisted men while they are aboard ship at sea, tourists remotely exploring foreign cultures, or STEM experts preparing the next generation for careers in the sciences, enhancing the degree of embodiment of the remote user is beneficial any time human interaction takes place. Being physically present is the ”gold standard” for interpersonal communication, and the closer we can get a remote user to being there in their own body the more effective the technology will be.

The last example, providing remote STEM experts a body for preparing the next generation for careers in the sciences, is the context for this project. This project uses a Making based model called ”Making as Micro-Manufacturing”, which was developed as a model for motivating STEM participation and providing a curriculum to teach both a STEM mindset and STEM skills[6,7].

In this model, high-variability low-volume products are manufactured for a specific, real-world purpose using practical engineering concerns. In the specific case chosen for this project, practice-based learning is implemented with high school students who learn technical aspects of making such as basic electronics, 3D printing, and assembly, as well as learning critical manufacturing skills such as production scheduling, inventory management, and supply-chain management.

The schools in which these students learn are located in economically distressed communities that have under-resourced schools. They are physically distant from large concentrations of STEM experts, located in deeply rural areas at the southern border of Texas. These classes are not expected to have in-house STEM experts to provide technical expertise. The distance of these school from larger population centers in general, and from STEM experts in particular, precludes the feasibility of in-person instruction. Therefore, a technologically-assisted solution is needed to provide the required STEM expertise to these classes.

The high school students taking part in the program will attend a daily class at their local school as part of their typical school day, where they will be taught making and micro-manufacturing skills. The local teacher is not required to have any STEM expertise or inclination. A remote STEM expert, acting as both technical instructor and mentor to the high school students, will teach the required skills and lead the class in an ongoing project.

The project that these students will work in is divided into a series of scaffolded project cycles. The end goal after each project cycle is to gain the skills needed to manufacture instructional hands-on science kits for use in local elementary schools. In each cycle, the students will take a larger and larger role in both manufacturing and technical work, until they are working as a full manufacturing center for making the kits in sufficient quantity to be used in the local elementary schools as a practical, real-world implementation of the skills they have learned.

Based on previous work with the ”Making as Micro-Manufacturing” model, a formal curriculum is followed with illustrative slides, videos, references, etc. A class begins with a recap of completed and in-progress work, as well as a big-picture review in the context of the current cycle. Afterwards, there is instruction on the current topic of the day. Thereafter, students engage in hands-on tasks for the remainder of the class period. This hands-on work is the majority of the class period.

MentorCorps

Training teachers to be STEM experts is unlikely to be cost effective. The cost of hiring a trainer to educate a teacher face to face is prohibitive, and even on-line training reaches a price point in the hundreds of dollars per teacher[8] Even after such training, a teacher without a STEM degree is still disadvantaged compared to a STEM-focused expert.

The solution to this issue is the recruitment and hiring of STEM-major undergraduate students. These students have a strong technical background and a STEM-focused mindset. There is a large pool of these individuals at each of the many universities spread across the country, providing a practical and replicable pool of STEM experts for the project. An additional benefit of using STEM-major undergraduate students is that they have fixed schedules and are typically free at specific times within the normal school day.

To this end, we have recruited several STEM-major undergraduate students from Texas A&M University to act as in-classroom mentors. These students are hired to act in partnership with the local high school teacher. They serve as STEM experts, technical instructors, and mentors to the students. Recruiting was accomplished through a general advertisement to university students, targeted specifically at those students who had a STEM major. From the pool of applicants, those with the strongest experience with teaching, working with children, and relevant technology experience were brought in for interviews. Interviews were used to further narrow the pool based on interpersonal skills and additional experience details gleaned during the interviews. Ultimately, from a pool of those who scored highest in these factors, those who best fit availability needs were selected as mentors.

Training for the mentors is accomplished through twice-weekly meetings. One meeting is an "all hands" meeting that encompasses mentors performing similar roles from other projects and discusses teaching methodologies, classroom management, and mentor experiences in the classroom. The second meeting is specific to the mentors on this project and covers the week's lessons, specific technical instruction, and a more detailed examination of any in-class issues or developments that occur.

These students are located at the main university campus, hundreds of miles from the students they will be instructing and mentoring. Their instruction for their responsibilities in the distant high school is accomplished on campus. This on-campus location is convenient for management and training, but is obviously incompatible with physically placing these mentors into the high school classrooms.

The project will use technology assistance to give them bodies in the remote classrooms, using these mentors and their experiences, as well as those of the high school students, to evaluate this project.

Pilot Study

A pilot study was undertaken to gain an initial understanding of the project. High school students were recruited to take part in a four-hour study, and we used this data to compare a co-located instructor to a telepresence instructor. The objectives of the study were to examine how telepresence and co-located experiences differed in using space and physical objects during hands-on learning, exploring what types of verbal communication was used during this learning, and to measure the impact these different instructor modes had on learning a hands-on topic.

In the pilot study, sixteen high school students were instructed in a variety of tasks, with eight being taught by a co-located human instructor and eight being taught by a telepresence instructor. Students were paired together into teams of two. The instructor was a graduate student who was familiar with the topics and in a STEM field. We had the students perform a number of tasks and then used surveys to gather information on the effectiveness of the two instruction methods.

Students performed tasks spread across several activities. Students soldered components, used a hot glue gun, used heat-shrink on wires, built electronic circuits, designed 3D components using

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
5	4	3	2	1

Table 1: Questionnaire Response Options

TinkerCAD, and used a laser cutter. A lecture was given on these topics, followed by hands-on and independent work in these activities.

Each four-hour study was composed of two projects, with each project repeating the same three modules. In the first module of the first, students were given a lesson on using TinkerCAD, an entry-level online 3D object design tool. After approximately ten minutes of instruction, students were given thirty minutes to work on their design in TinkerCAD. At this point the instructor's role was direct interaction with the students to answer questions and assist in problem resolution.

After the TinkerCAD module, students were given a lesson on using the laser cutter. As there was only one laser cutter, students then worked on the laser cutter sequentially, with one pair of students executing their laser cutter job while the remaining students worked on the third module.

The third module began with a lecture on soldering and circuit assembly. This module included work with a hot glue gun, soldering, and heat-shrinking wires. After approximately ten minutes of instruction, students worked on their project. This happened concurrently with the laser cutter work of module two. During this time the instructor was in place to provide answers to questions and direct, one-on-one assistance.

After the completion of the first project students were given a break, and then a second project with the same phases was undertaken. In the second project the phases were performed without a preceding lecture and instead relied on what the students had learned in the first project.

Results

After completion of the study, surveys were given to the students to capture their experiences with the co-located instructor and with the telepresence instructor. Students rated their answers on a scale from 1 to 5 (Figure 1), and results of the ”gold-standard” physically present instructor were compared against those of the instructor with a telepresence body. The results were analyzed with the Kruskall-Wallis H test to determine statistical significance.

Students reported no significant difference in ease of understanding the material between the co-located instructor and the telepresence instructor. Students were asked about their understanding of the lecture on soldering, hot glue gun, heat shrinking, TinkerCAD, designing the project, and the project's electronic circuits. This result is not surprising, as a typical lecture does not often depend on kinesics and proxemics, and paraverbal features in communication channels are largely still present in the telepresence robot to the degree they were used in the lectures to the high school students.

When students devolved from the lecture mode to team work, the lack of a body for the instructor

		Mean Score		Kruskall-Wallis H Test	
Category	Topic	Co Present	Tele Present	Chi Square	Statistical Significance
Hands-On (Project 1)	Understanding designing the project	4.67	4.14	4.078	0.043
	Understanding laser cutting	4.67	4.0	4.571	0.033
Independent Work (Project 2)	Successfully understand how to perform the tasks in TinkerCAD	4.77	3.86	6.585	0.01
Future Interest	Interest in doing future work with a hot glue gun.	4.67	3.714	5.744	0.017
	Interest in future work designing projects	4.67	3.714	5.11	0.024
Overall Interaction	Ability to communicate effectively with the instructor	4.55	3.86	3.932	0.047

Table 2: Responses with statistically significant differences

began to make an impact, as shown in Figure 2. In the hands-on section of project one that followed each instructional lecture, students expressed a greater difficulty understanding the process of designing the project and in understanding the laser cutting instruction with the telepresence instructor. While working independently on project 2, students expressed a much greater degree of difficulty working with TinkerCAD in the case where the instructor was telepresent compared to when he was physically present.

These results reflect the reduced communication channels between the instructor and the student. When the student is given a hands-on task, the reduced communication channels impacted the ability of the instructor to convey information. One of the key metrics that demonstrates this was that students provided significantly lower scores for ”Communicate Effectively with Instructor” when the instructor was telepresent instead of co-located.

Interestingly, students also gave lower scores to the telepresent instructor for questions about their interest in doing future work. In response to questions about their interest in doing future work designing such projects and in working with hot glue guns, students gave the telepresent instructor significantly lower scores. It is possible that this indicates a lack of the ”human connection” to the instructor in the telepresent mode, which is a key issue to address when attempting to provide mentorship and role models to students.

Telepresence Education

The ideal solution, as already mentioned, would be to co-locate the STEM undergraduates at the high schools so that they could provide hands-on instruction. Having a body physically present is the ”gold-standard” for education. Being physically present allows for the full benefit of human communication channels. A physically present person has the benefit of kinesics, proxemics, and paraverbal features in their communication channels, which play an important role in conveying information and ideas[9].

This solution is impractical, however, as these deeply rural schools are hours of travel time away from the STEM experts who will be assisting in the classes. While this work uses the specific case of rural border-region Texas schools, this issue arises in any instance where the instructor and student cannot be co-located.

Without a body in the classroom, several communication channels are reduced or severed, even with the use of teleconferencing to carry voice and image. Gestures, shared gaze, the use of space, movement, body positioning and posture, and a host of other communication channels are lost. The use of simply walking around is a critical teaching and student assessment tool[10].

The solution to this issue is to provide the STEM instructor with a body through the use of a telepresence robot. This solution is not intended as a perfect solution that completely replicates the gold-standard of being physically present. Instead, the goal is to recreate as many of the lost benefits of having a body as possible.

This recreation of the benefits of having a body is the goal of our research. We will be looking at enhancements and additions to the core idea of having a telepresence body, exploring how we can recreate lost communication channels and restore fidelity in reduced communication channels, and evaluating the effectiveness of our solutions.

Cyberlearning Telepresence Project

Here we will describe the overall timeline for our project for the first two phases of the project. The first two phases of the project mirror the two modes of the pilot study in that one phase gives an extended view of our baseline teleconference instruction while the second introduces telepresence robots and provides an equal length of instruction time and experience. We will briefly discuss future plans beyond the first two phases.

Phase 1

The initial work on this project was established as an extension of previous work with Webb Consolidated Independent School District (CISD). Webb CISD is characterized by a rural setting serving a homogeneous population of Hispanic students. Classes were established at Bruni High School, and expanded to the neighboring Jim Hogg County Independent School District (ISD), where a class was established at Hebbronville High School.

Two members of our research team went to Bruni High School and Hebbronville High School in the Summer of 2019 to examine and verify facilities, to deliver and set up remote teaching and Making materials, and to gain a familiarity with the classrooms that the STEM mentors would be mentoring and teaching in. The STEM mentors themselves have not been to the classrooms physically, and have only been present through technological assistance. The overall goal was to get a sense of the capabilities of the classrooms and to verify that the classes would have the proper starting conditions and materials for the project.

The first phase of the project establishes a baseline using the most common, though also least-embodied, technological assist: teleconferencing. For this phase, we use the common and reliable application Skype to provide the teleconferencing, beginning in September of 2019 with three undergraduate STEM mentors. STEM Mentors come into a dedicated teaching space in our lab every day to teach and mentor the classes at Bruni and Hebbronville. A computer, webcam, and microphone complete the setup on the mentor's end, and a matching ensemble with a much larger screen is located in each of the classrooms.

One of the STEM mentors was a continuing instructor from earlier research. Two STEM mentors were recruited from the population of undergraduate STEM majors. Applicants were reviewed for teaching experience, Maker experience, and experience interacting with younger students, with an additional culling of the applicants based upon in-person interviews. Final selections were based on the availability of those applicants who scored the best in these areas. Going forward, all mentors are recruited with this method.

Due to the nature of undergraduate class schedule, it is often not feasible to schedule a mentor at the same time every day. There have been instances, for example, where one mentor is scheduled Monday, Wednesday, and Friday, and a second mentor teaches and mentors on Tuesday and Thursday. Communication to ensure cohesiveness of the lessons and the pacing is handled by face-to-face meetings and group messaging tools such as Slack.

Mentors take part in two face-to-face meetings with research staff each week to ensure cohesiveness of teaching approach, mentor knowledge of subject material, and address any problems or issues that have arisen.

Data collection is being accomplished through a number of different mechanisms. Curriculum materials, tentative schedules, updates on current progress, and daily recorded audio and video is stored on a Google drive. The proximity of all the STEM mentors allows weekly meetings to discuss classroom development, issues that have arisen, classroom pacing, and any other topics that need to be discussed.

Mentors and high school students are also given surveys to collect their impressions, feelings, and reactions. We can assess the students' comfort level and the accessibility of the instruction, which provides guidance to our ongoing mentor training. Likewise, understanding the perspective and experience of the mentors gives both context for understanding student feedback and a front-seat view of the mentoring experience.

The goal of phase one is to provide a test bed to fully establish the processes and procedures for the remote classes. It also allows the mentors to be deeply trained in their roles.

Phase 2

The second phase of the project is the introduction of unenhanced telepresence robots, manufactured by OhmniLabs. These models have a 10.1" HD IPS touchscreen, a 4k 13-megapixel forward facing camera, and a downward facing navigation camera. The forward-facing camera has tilt capability. The robot itself is capable of multiple speeds and zero-radius turns, and has a battery life of six hours.

In this phase, each school will have one robot, which will be used by the mentor to teach the class. The mentor will have the capability to drive the robot around the classroom, monitor students work directly, and have a more "present" experience in the classroom.

Research in this phase will focus on both the mentors and the students. It will examine if and how the introduction of the robot distracts or enhances the classroom, the impact of mobility on communication and resolving student issues, and a number of other factors. The same data gathering measures will be used in phase two as were used in phase one.

The robots will be introduced to the high school classes in a rolling fashion to better isolate the impacts of the introduction of the robots. The mentors will receive training in driving and teaching with the robots before they are used in the classrooms.

Future Phases

Future phases of the project will examine adding communication enhancing technologies to the base telepresence experience. The first enhancement is the use of a near-focus camera that allows the remote mentor to get a close, specific view of the student's work. This will be used to capture the student's project and workspace and present that to the remote mentor as an augmented reality image. A second camera, located at the remote mentor's site, will capture the mentor's hand movement in the augmented reality space. This video will be composited with the original video of the students project and displayed on a second screen located on the robot, giving the student a virtual reality representation of the mentor gesturing to their project.

Future enhancements beyond this work will add additional augmented and virtual reality features to implement more channels for communicating gesture, gaze, and other non-verbal communication mechanisms. These enhancements, as in phase two, will be introduced in a rolling fashion so that the impact of each phase can be isolated and examined.

Future Work

Future work for this project will further evaluate enhancements, not to just communication channels and modes, but also to other aspects of a telepresent body. The issue of human comfort in the presence of a telepresence robot is one area of investigation. A robot is very obviously not a human being, and there are a number of potential options to make a robot, if not more human, more socially acceptable.

The mentor side of the robot experience is also ripe with opportunities for investigation. Navigating a robot easily and naturally is often difficult, and novice drivers have clumsily run into countless obstacles. It is useful to give the robot's user the sense of ”being the robot” in the remote space, without forcing the mentor to wear virtual reality goggles or other cumbersome, focus-restricting equipment. There is also fertile ground in the discussion of the complexities of setting up, running, and improving the mentor program and even the impact participation in the program has on the college experience of the mentors.

Additional measures of the impact of the project are another area for future expansion. Long-term analysis of whether high school students in the study are more likely to select other science-based electives, evaluation of student apprehension about participation in the program, and review of the effectiveness in creating a welcoming learning space. These measures can feed back into ongoing phases of the program to provide iterative improvements of the process.

There are also numerous applications outside the high school classroom. Students are often in locations outside the reach of conventional instructors, such as sailors at sea who need to attain hands-on technical training from shore-bound instructor and specialist professionals who geographically distant from technicians.

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