iVisit-Communicate for AEC Education: Using Virtual Humans to Practice Communication Skills in 360-Degree Virtual Field Trips

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Abstract: To prepare graduates for the dynamic and complex working environment in the architecture, engineering, and construction (AEC) industry, educational institutions have distinctly emphasized the significance of communication skills. Field trips are a widely utilized strategy to provide students with a situated learning setting where students can communicate with professionals onsite. However, several challenges limit the application of this strategy, and virtual field trips become a potential and promising supplement or alternative approach. This study discusses the pedagogical use of a virtual field trip experience augmented with conversational virtual humans—*iVisit-Communicate*—to produce realistic field trips for students to practice their communication skills. This virtual experience is supported by immersive computing (i.e., 360-degree virtual space) and conversational virtual human technologies. *iVisit-Communicate* simulates two types of communication to provide student-professional verbal communication opportunities: guided scenario and conversational scenario. The paper provides a detailed description of the technical and pedagogical development of *iVisit*-Communicate components followed by a student-centered experiment, focusing on measures such as system usability, sense of presence, and communication skills of students. The contribution of this study is to provide an in-depth understanding of the significance of integrating communication opportunities in virtual field trips and illustrate how such on-the-site opportunities successfully facilitate students' communication practices. **DOI: 10.1061/JCCEE5.CPENG-5165.** © *2023 American Society of Civil Engineers.*

Introduction

The architecture, engineering, and construction (AEC) industry involves several parties to communicate frequently with each other in different phases of projects due to the dynamic and complex nature of the AEC industry (Wen and Gheisari 2020b). Research and studies have found that efficient and frequent communication is essential in different project phases and leads to better construction performance. For instance, successfully communicating facility requirements and prerequisites among stakeholders in the early phase of the project can improve the quality of the projects in the delivery process (Du et al. 2016). Since communication plays such a critical role in the entire life cycle of projects, educational institutions have emphasized preparing graduates' communication skills for the dynamic and complex working environment. For example, the ability to communicate effectively has been determined as one of the key outcome requirements by the Accreditation Board for Engineering and Technology (ABET). However, while communication-intensive courses and other relevant skills development methods have been applied in colleges, graduates' communication skills tend to be still weak from the industry's perspective (Clement and Murugavel 2015; Sheth 2015).

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In AEC-relevant programs, student-professional interactions have been recognized as an effective method to practice communication skills (Eiris et al. 2022). The field trip is one of the most commonly utilized strategies to allow students to interact with professionals and gain communication opportunities, particularly in construction-relevant curricula (Eiris Pereira and Gheisari 2017). Within field trips, learning during students' exposure to the construction activities and procedures on the jobsite drives verbal communication between students and professionals. Compared with communicating in a traditional classroom setting, field trips support a situated learning setting, where learning and communication are situated in a specific construction-related context and embedded within a particular construction-related physical environment (Lees and Noddings 2016). However, field trips have many challenges that hinder students from such situated communication experiences. Some of the challenges include large class sizes, short field trip duration, and the inability to see or hear in a crowded and noisy environment of a project site. These issues diminish the opportunity for each student to communicate with the professionals on site. Public health concerns, such as the COVID-19 pandemic, have also significantly reduced opportunities for educators, schools, and AEC-related industries to conduct field trips; thereafter, student-professional communication practices are further reduced.

Virtual field trips are a potential alternative or a supplement to traditional field trips to provide students with a situated learning setting. Previous studies have indicated that students can develop spatiotemporal awareness in a virtual field trip while perceiving more information than a conventional in-class course delivery (Wen and Gheisari 2020a). However, such virtual field trips have supported minimal opportunities for student-professional communications within their virtual environments. This study develops a virtual field trip platform—*iVisit-Communicate*—embedded with an intelligent communication system. *iVisit-Communicate* provides student-professional verbal communication opportunities by simulating two types of communication scenarios: guided scenario and conversational scenario. In the guided scenario, students can practice active listening skills where they must fully concentrate on what is being said rather than passively hearing the message (SkillsYouNeed 2022). In the conversational scenario, students can practice both active listening and written communication skills, where the latter refers to exchanging information in writing through letters, reports, and texts (Sharma 2022). The logical programming enables the intelligent communication system to provide feedback and hints based on students' specific input, simulating a natural two-way communication process. A pilot study is conducted within the context of a mechanical and plumbing systems field trip to assess the *iVisit-Communicate* in terms of usability, sense-of-presence, as well as objective and subjective assessments of students' communication skills. The outcome of this study provides a better understanding of virtual field trips empowered with conversational virtual humans to offer students on-the-site communication opportunities. Specifically, this study aims to advance knowledge in the application of 360-degree virtual field trips embedded with communication opportunities and provide answers to how such opportunities facilitate students' communication practices.

Relevant Studies

Virtual Field Trips

Field trips are widely applied in construction programs as they support students' technical and practical knowledge and aid them in reinforcing the core concepts taught in class (Wen and Gheisari 2020a). Eiris Pereira and Gheisari (2017) conducted a national survey to collect descriptive data about field trip implementation from construction programs across the United States. It was found that construction programs have implemented at least one or two field trips per semester for their core subject areas. Such field trips have provided students with opportunities to communicate with AEC professionals and increase their career awareness, which may not be accessible in a classroom setting (Adedokun et al. 2012; Murray and Tennant 2016). However, challenges associated with the spatiotemporal nature of the construction projects present the most significant barriers to implementing field trips in the curriculum. For instance, it is not practical for students to see or hear the entire construction process in the short field trip duration (Eiris Pereira and Gheisari 2017). Short field trip durations, along with the large class sizes and the noisy working environments, further diminish students' opportunities to verbally interact and communicate with professionals on the jobsite.

To overcome barriers to traditional field trips, researchers have explored virtual field trips that provide easier access to construction sites. The virtual field trip is a journey taken without actually making a trip to the site and may take place via the Internet or be delivered using other technologies (Finch and Wing 1996). However, the previous literature shows that very few studies have embedded the communication component in virtual field trips.

The virtual field trips were mainly developed using captured-reality technology. This technology involves capturing images or videos of the construction jobsites to create the spatiotemporal context for the virtual field trips. This approach has been widely applied over the last three decades. The images or videos could be pre-captured or delivered in real-time, but the majority of these trips were created using pre-captured content. For example, Landorf et al. (2015) captured 75 photos of a construction jobsite, which were taken every one or two weeks over the course of construction. During such virtual field trips, students can observe the surrounding environment and equipment on site and perceive the dynamic nature of the construction throughout time. However, such precaptured trips focused mainly on providing the spatiotemporal context of construction jobsites, while the communication component was excluded from the trip primarily due to technical limitations. On the contrary, virtual trips delivered in real-time have the potential to enable live communication between students and construction professionals onsite. For example, in a series of studies conducted by Jaselskis et al. (2011), a construction professional was present on a construction jobsite, discussing details about the construction project and activities while the video imagery and voice information were transferred to the classroom in real-time via wireless internet. In these studies, both the professionals on the site and the students in the classroom were equipped with microphones for communication purposes. Although the inclusion of the communication component was an advantage of this live-streaming method, the high volume of background noise caused by construction operations and wind reduced the quality of verbal communication (Jaselskis et al. 2011). Furthermore, considering the entire class sharing microphones and interacting with only one professional, it was not practical to provide a communication practice opportunity for every individual student in this study.

With technological advancements, 360-degree panoramas and videos have also been introduced to create virtual trips. They can be captured using cameras with multiple fisheye lenses to create equirectangular projections of the surrounding environment of the cameras. Compared with traditional images and videos, 360-degree contents are unbroken views of the complete environment encircling an observer, providing a virtual experience with a high sense of presence (Eiris et al. 2022; Higuera-Trujillo et al. 2017). In a study by Eiris et al. (2020), a 360-degree panoramic field trip was created, incorporating interactive buttons, augmented information, and virtual humans. It was found that these guided virtual tours were easy to utilize, produced highly realistic representations of the jobsite, and offered a high sense of presence to the participants. Various virtual field trips have been implemented for specific purposes, such as developing spatiotemporal awareness and practicing collaborative problem-solving skills (Eiris et al. 2021, 2022; Maghool et al. 2018). However, the communication aspect has not been adequately focused on, and no previous studies have comprehensively explored the potential of virtual field trips in providing students with opportunities to practice their communication skills.

Communication in Virtual Environments

Virtual environments are digital spaces where users can navigate the space and manipulate and interact with virtual objects, such as 3D models, text, and audio (Eiris et al. 2022). Virtual environments have been widely applied in the AEC domain for communication purposes within different contexts, such as building inspection, facility management, safety training, construction education, and design and review (Wen and Gheisari 2020b). Literature found that virtual environments support rich communication practices from the oral, listening, and visual aspects. For instance, the voice chat and the text-based tool are widely used in multiple studies in the AEC domain to facilitate oral and listening communication either synchronously or asynchronously. Visual communication processes image-based information such as drawings and models, representing a specifically essential communication method in the AEC domain. The virtual environment has unique advantages in supporting communication in the AEC domain, as visual sharing affordance is a built-in feature in such an environment. For instance, users in the virtual environment can easily share drawings or viewpoints, exchange files, and make annotations to discuss details or collect other users' attention on designated objects (Anderson et al. 2014, 2017; Cheng et al. 2018; Pham et al. 2018). The capability of supporting several communication aspects at the same time makes virtual environments an effective place to communicate. In virtual environments, remote users can observe and discuss their points of interest in a shared workspace and share drawings, models, and other files as needed, which simulates a natural communication process in the real-world working environment.

In some studies, virtual humans are used as a medium to facilitate communication (e.g., Anderson et al. 2014; Dossick et al. 2015). Virtual humans are computer-generated entities that replicate humans and serve as vehicles to interact with other objects, humans, or systems (Eiris and Gheisari 2017). The virtual humans' gestures, positions, and movements have been found specifically beneficial for nonverbal communication in 360-degree virtual spaces, where users can freely rotate their view ranges to observe their data-rich surrounding environment (Wen and Gheisari 2021). For instance, finger-pointing gestures help the virtual human attract users' attention to designated objects and enhance a mutual understanding of discussed objects (Shi et al. 2016). Similarly, virtual humans' position, orientation, and movement (i.e., walking from one location to another) provide clear cues to others regarding the discussed objects and reduce coordination latency (Anderson et al. 2014; Wen and Gheisari 2021). In this study, students were exposed to a significantly data-rich 360-degree virtual environment that they were not likely familiar with, but such features made the virtual human an effective communication medium on the virtual field trip experience. There are two forms of virtual humans: (1) avatars that are controlled by live humans; and (2) agents that are controlled by computers (Badler 1997). In most studies that applied virtual humans, communication happens between real humans, and continuous information is transferred from a real human to other real humans through avatars. Information can also be transferred both ways between the human and the agent. For example, Goedert et al. (2011) conducted a study where the information was provided from a real human to a computer-controlled agent. After the computer program ran the analysis for the construction process of a facility, the analysis results were provided from the agent for the real human to optimize time and cost for the construction process. In the medical domain, virtual humans have been applied as partners in interpersonal communication scenarios, facilitating the teaching, training, and testing of medical students' communication skills during patient interviews (Cendan and Lok 2012; Lok 2006). It was found that the virtual human appeared authentic, stimulated medical students to ask questions during the communication process, and provided a moderate sense of presence. Although studies have recognized virtual humans as communication facilitators in virtual environments, mainly in the medical domain, no studies have explored their use and benefits to enhance communication skills in the AEC-relevant educational programs.

Research Method

The goal of this study is to explore the pedagogical use of 360-degree panoramic field trip experiences enhanced with conversational virtual humans—*iVisit-Communicate*—to produce realistic field trips for students to practice their communication skills. To be more specific, this study tries to understand the follow two research questions:

- Research Question #1 (RQ #1): How does *iVisit-Communicate* facilitate students' communication practices in a problem-based learning scenario?
- Research Question #2 (RQ #2): How does the two-way communication component enabled by *iVisit-Communicate* affect students' learning experience in the virtual field trip?

To investigate these research questions, *iVisit-Communicate* simulates two types of communication opportunities (Fenner 2021a, b) within the virtual field trip experience:

1. *Guided Scenario*: a professional-to-student one-way communication that simulates a guided field trip experience with the main goal of covering the learning objectives of the field trip. This guided scenario represents one of the most commonly observed learning experiences during a field trip and has been widely simulated in virtual field trip applications (Arslan 2004; Eiris et al. 2021, 2022; Finch and Wing 1996; Landorf et al. 2015; Mei and Wing 1999; Wilkins and Barrett 2000).
2. *Conversational Scenario*: a two-way communication that simulates interactive conversations between students and professionals on the jobsite. The main goal of this communication opportunity is that students can use the knowledge gained from the previous guided scenario to discuss and solve a real-world problem through conversations with professionals on the jobsite. This scenario supports a problem-based learning setting, where students are situated in the context of problems they are asked to solve (Capon and Kuhn 2004). In this conversational scenario, the professionals on the jobsite act to facilitate the problem-solving process rather than to provide knowledge.

This study has three research steps: content design, system development, and assessment (Fig. 1). In the content design phase, specific goals and learning objectives of the field trip are designed. Based on these goals and learning objectives, learning contents for the guided scenario are generated, and the required virtual human

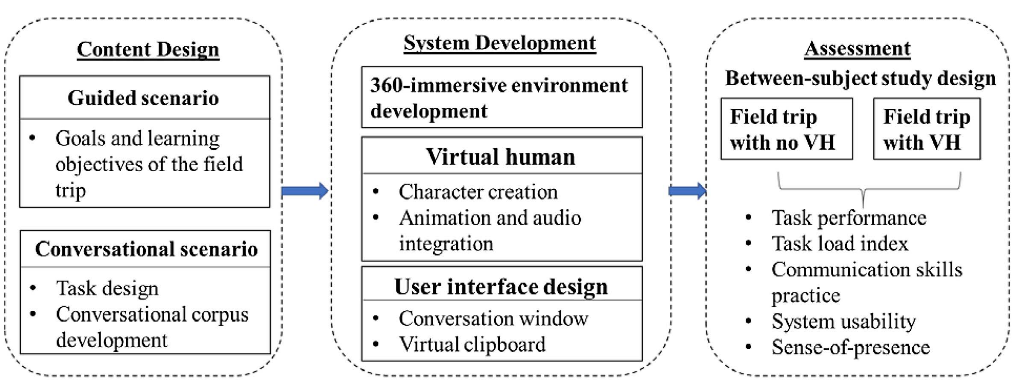

Fig. 1. Research method.

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narratives are created. Then, a conversational scenario is also designed based on the learning objectives, which presents a real-world problem for students to apply the knowledge they just learned in the guided scenario. In the system development phase, a 360-degree immersive environment is developed and augmented with supplementary information. A virtual human is also modeled and integrated into the virtual site with proper animation and audio. Animations enable the virtual human to perform several types of gestures and body movements and they are set to be aligned with the narrative audios covering the field trip learning objectives. Then the user interface of the *iVisit-Communicate* is developed, which includes the conversation window for chatting with the virtual human and a virtual clipboard providing navigation features and reviewing field trip knowledge contents.

In the assessment phase, with a specific emphasis on the two-way communication component in the system, this study uses a between-subject design where students are randomly allocated to one of the following two conditions:

- VH condition: two-way communication between students and the virtual human is integrated.
- No-VH condition: two-way communication between students and the virtual human is not integrated.

iVisit-Communicate is embedded and distributed using the Qualtrics online platform so that students can participate in this virtual field trip remotely. A computer, a mouse, a keyboard, and a stable internet connection is required for participation. During the assessment process, students need to (1) understand and sign the consent form, (2) fill out a pretrip survey, (3) download the *iVisit-Communicate* as an executable file and experience the virtual field trip; and finally, and (4) fill out a post-trip survey. In the consent form, students are carefully introduced to the purpose and steps of the study. This study uses five measures for students to evaluate *iVisit-Communicate* from the following aspects. To answer RQ #1, task performance and communication skills are collected. To answer RQ #2, task load index, sense-of-presence, and system usability are collected. Then, based on the characteristics of the collected data (e.g., sample size, normality), a set of proper statistical tests are used. The following measures are used in this study:

Communication Skills (for VH condition only): STEM Interpersonal Communication Skills Assessment Battery (Wilkins et al. 2015) was used in this study. This battery was designed to measure an array of communication subskills, including active listening, assertive self-expression, and receiving and responding to feedback (Rubin and Martin 1994). In this study, 20 psychometric properties of interpersonal communication knowledge assessment were adapted for students participating in VH Condition. The survey was presented to students in the VH Condition using a 5-point Likert scale that scaled from strongly disagree to strongly agree.

Task Performance: Given the complexity of the communication process, measuring the communication outcome is an important approach to understanding its effectiveness (Fischer et al. 2019). In the context of this study, the task performance represented the communication outcome. Task performance was evaluated from two aspects: the time spent to complete the task and the accuracy of the task. Specifically, in this study, task performance is an indirect indicator of communication practice, where an effective communication practice is indicated by effectively solving a task (i.e., solving the task in a shorter time with higher accuracy).

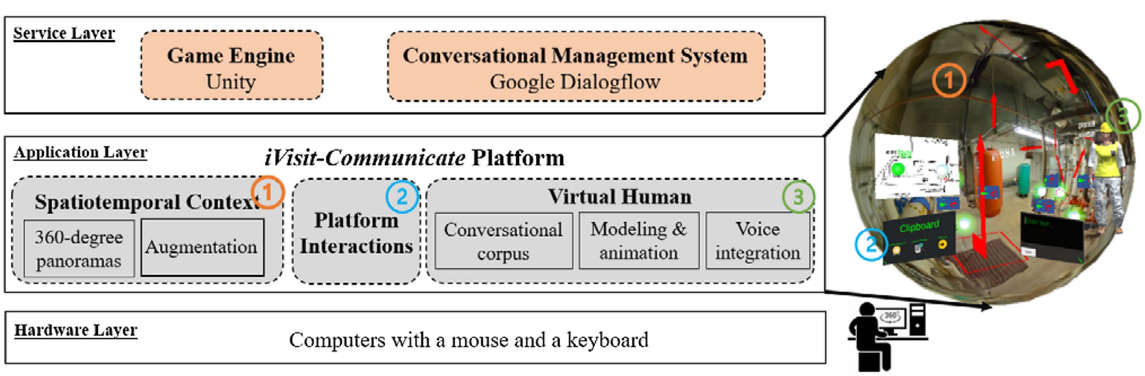
Task Load Index: NASA task load index was adapted to measure the subjective mental workload of performing a task (National Aeronautics and Space Administration 2020). The task load index allowed students to subjectively assess six aspects of their task load: mental demand, physical demand, temporal demand, performance, effort, and frustration.

Sense-of-Presence: Sense-of-presence refers to the sense of being in a mediated or computer-generated environment displayed by technical interfaces (Slater and Wilbur 1997). Achieving sense-of-presence has been considered a crucial aspect of a successful virtual experience, as it can positively affect various output measures such as task performance (Ragan et al. 2010; Weech et al. 2019). In this study, the sense-of-presence was assessed using five statements on a 5-point Likert scale (Slater et al. 1994; Usoh et al. 2000).

System Usability: The system usability scale (SUS) was adapted to measure the ease of use, satisfaction, effectiveness, and efficiency of system design (Brooke 1996). It has been widely applied to access the usability of various products or services, as it is quick and easy, cost-effective, technology agnostic, and the score is easily understandable by a wide range of people (Bangor et al. 2009). In this study, SUS was applied to understand whether students can actually complete their tasks and achieve their goals for the virtual field trips (effectiveness), the extent to which they expend resources in achieving their goals (efficiency), and the level of comfort they experience in achieving their goals (satisfaction).

iVisit-Communicate Platform Development

The system architecture of *iVisit-Communicate* consisted of three layers: service, application, and hardware [Fig. 2(a)], which was



(a) (b)

Fig. 2. (a) *iVisit-Communicate* system architecture; and (b) platform components.

built on the outcomes of a series of iVisit-related studies that utilized interactive 360-degree panoramic digital environment to deliver virtual field trip experiences (Eiris et al. 2021, 2022).

The service layer enables the hosting of all application layer elements, in which the research team conducted all system development activities. In this study, the service layer utilizes the Unity game engine as the middleware enabling the game development and Google Dialogflow as the conversational management system. Specifically, all interactions in the application layer, including the communication process, are programmed and enabled using Unity, and Google Dialogflow manages the conversations between students and the virtual human by recognizing students' input and designating corresponding responses. Google Dialogflow is a well-developed natural language understanding platform widely applied to support virtual conversational assistants on Android, iOS, and Windows Phone smartphones (Chen, n.d.). The application layer is the only layer students have access to and includes three major components: spatiotemporal context, virtual human, and platform interaction [Fig. 2(b)], which will be described in detail in the following sections. The hardware layer represents the devices that allow students to physically engage in *iVisit-Communicate*. While Unity supports multiple types of devices, this study used traditional computers with a mouse and keyboard as the hardware layer mainly for two reasons. First, such a setting has been widely utilized in people's lives; for instance, among all households in 2018, 92% had at least one type of computer (US Census Bureau 2021). Therefore, it is easily accessible to the majority of the targeted audience of this study. Due to a high level of familiarity, the applied hardware setting would not introduce an extra learning process for hardware utilization. Second, the two-way communication in the conversational scenario requires accurate and clear input from the user (student)'s side, which is perfectly supported by a keyboard.

Spatiotemporal Context

Creating the 360-degree immersive environment requires three steps: authoring, visualization, and augmentation & interaction. First, the authoring process creates an equirectangular science of the jobsite by stitching individual captures into a single scene (Wen and Gheisari 2021). Then, the visualization step entails remapping the equirectangular images into spherical coordinates to generate an explorable panoramic environment. Game engines can be used to create and render such a panoramic environment that offers a unique sense of presence and immersion. Finally, the augmentations and interactive objects are incorporated into the 360-degree immersive environment. Texts, arrows, and images are some augmentations in *iVisit-Communicate*. The purposes of augmenting the environment include supplementing the environment with the necessary information that may not be visible in the image (e.g., construction drawing, air and water flow, force direction and analysis), highlighting the objects being discussed in the trip, and facilitating students' concentration and understanding on the designed learning contents. Interactive objects (i.e., hotspots) associated with designated augmentations are programmed in the system to prevent the environment from being overinformative. Since the amount of augmented information is massive in every scene, designated augmentations will only be visible after their associated hotspot is activated. During the trip, students would follow the learning contents presented by the virtual human and are prompted to activate the hotspot associated with the current discussed contents.

Virtual Human

This study used an agent type of virtual human controlled by the *iVisit-Communicate* system. Communicating with a computer-controlled agent cannot cover a wide range of topics and information as communicating with a live-human-controlled avatar, as the conversational corpus for the agent is preprogrammed and only include a limited number of responses. However, communicating with an avatar requires at least one professional to be available and responsible for every individual student's conversational scenario on the virtual field trip, which was not feasible. Therefore, using a computer-controlled agent, *iVisit-Communicate* could provide students with communication scenarios that are controllable, repeatable, and available anytime and anywhere.

Virtual Human Conversational Corpus

A conversational corpus is developed to enable two-way communication between students and the virtual human. The conversational corpus includes what the users will say to a virtual human (stimulus) and what the virtual human will say back (response) (Rossen et al. 2009). A real-world problem was created to provide a context where the conversations are suited. Such context would also determine the purpose and scope of the two-way communication in the conversational scenario. The rationale for designing this task is to ensure the task context aligns with the learning objectives of the field trip and supports students to reflect on and actively apply the information they have gained from the guided scenarios.

Initially, the conversational corpus was developed based on the research team's best guesses on what students may ask from the virtual human in the given context (stimulus) and the responses were created accordingly (Rossen et al. 2009). Then, the corpus was improved iteratively by frequently exposing students to interact with the conversational corpus. In this study, Virtual People Factory (VPF) was used to perform the irritative improvement process as it can support several mediums, including message interactions, images (including 360-degree ones), and other preprogrammed interactions (Rossen et al. 2009).

To iteratively improve the conversational corpus, the research team constantly exposed VPF to students in the development phase, where they would communicate about the designated task with the virtual human using texts, and then virtual human responses would be provided by VPF based on the initial corpus. All conversational data would be captured and stored in the database for further analysis. During the conversation, if students input an unrecognized stimulus, they would be encouraged to input more stimulus types by receiving a response, '*sorry, I don't understand, can you say it another way?*' Conversational data would be reviewed after students' interactions, and unrecognized stimuli and respective responses would be manually added to the corpus. The finalized conversational corpus is imported to Google Dialogflow, which can recognize students' stimuli and assign corresponding responses to students. Then, Google Dialogflow API is set up in Unity to enable data transmission between these two platforms, where Unity passes students' input to Google Dialogflow for processing, and then Google Dialogflow controls Unity to display the designated responses to students.

Virtual Human 3D Character Modeling and Animation

The 3D character modeling process uses 3D computer graphics software (e.g., Adobe Fuse CC and DAZ 3D). The virtual human clothing with the bright yellow color with proper PPE (e.g., hard hat, gloves, boots) is specifically selected to match the context and background of the field trip, which could ultimately lead to persuasion and credibility (Eiris et al. 2020). The modeled 3D

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character would be imported to the game engine. Proper animations are integrated from Maximo, which provides a wide range of animation clips that can be applied to 3D characters in the game engine. Some animations are imported to mimic a natural human pose (e.g., idle standing position), and others are specifically selected to support nonverbal cues. Nonverbal communication delivers messages via a nonverbal platform such as eye contact, gestures, body language, and distance (Littlejohn and Foss 2009). The nonverbal cues between professionals and students during real-world field trips play an important role in designing the nonverbal cues for the virtual human. Different nonverbal cues such as body orientation, walking, finger-pointing, and natural hand movements during talking were integrated into the virtual human to help students pay attention to specific objects or issues on the site.

Virtual Human Voice Integration

The audios are generated based on the previously-designed conversational corpus, using the text-to-speech technique. This technique turns texts into natural-sounding and smooth speech and is supported by various web applications, such as Google Cloud, Microsoft Azure, and IBM Watson Text to Speech. In this study, IBM Watson Text to Speech was used to generate the audios for the virtual human, which can generate various voices with different characteristics (e.g., gender, accent, age, speaking speed, and pitch) based on deep neural network training on real human speech (IBM 2021). The main reason to apply synthesized audio instead of real human sound is the iterative improvements and refinements of the learning contents and the conversational corpus. With frequent and unpredictable improvements in the communication contents, it is not practical to employ a real human sound, as it requires an audio recording process from the same person every time the content is updated and subsequently raises extra logistical challenges. The generated audios are then imported to the Unity game engine with proper file names. Meanwhile, file names for responses are configured in Google Dialogflow to connect the responses managed by Google Dialogflow and the audio files played by the Unity game engine. With a valid students' stimulus input in Unity, Google Dialogflow would assign the corresponding responses, and Unity would play the designated audio file to provide students with a response.

iVisit-Communicate Platform Interaction

To help students better navigate the field trip and interact with the system, two user interface components were created: a virtual clipboard and an input question panel. These two components can be minimized to provide an uninterrupted view of the 360-degree environment:

- *Virtual clipboard* helps students control and keep track of the field trip's progress. It contains three interactive buttons: (1) Learning objectives: allow students to review the learning objectives, (2) Lecture review: allow students to review the learning contents that have been discussed in the field trip, and (3) Site map: move to other scenarios on this site.
- *Input question panel* allows students to type in their questions or comments and is only available during the two-way communications between the students and the virtual human. Due to the limited accuracy of students' speech recognition in audio format, this study required students to type in their questions. But the virtual human's responses were in audio format.

Site Visit Case Study: *iVisit-Communicate* in a Mechanical Systems Course

Case Study Selection

To identify the effects and challenges of *iVisit-Communicate* in helping students practice communication skills, a case study field trip was conducted on a mechanical systems topic. Mechanical, electrical, and plumbing (MEP) systems are commonly hidden in different parts of the buildings: e.g., large equipment in closed rooms, ducts above a ceiling, or pipes inside a wall. This makes it difficult for students to recognize and be familiar with different components of MEP systems. With such unfamiliarity, students can hardly gain a comprehensive understanding of MEP systems simply via texts and photos in a traditional classroom setting (Mokhtar 2019). Consequently, the core subject area of MEP systems has been considered one of the top areas in the construction management curriculum that require field trips (Eiris Pereira and Gheisari 2017). However, traditional field trips in this subject area are usually conducted in hard-to-access, tight, and noisy spaces (e.g., mechanical rooms), where essential system components are not visible to students or are too complex to understand. Such issues may negatively affect students learning experience during the field trip. Furthermore, along with the safety and logistical concerns of conducting field trips, the public health concerns due to the COVID-19 pandemic have forced educators to significantly reduce or even cancel in-person field trips (Sun et al. 2022). Such limitations constituted the focus of this study on developing a mechanical system-focused field trip for an undergraduate-level course at the University of Florida (i.e., BCN4510C Mechanical Systems). This course required a field trip to the mechanical room of a commercial facility that had been canceled due to COVID-19 restrictions. Therefore, a virtual field trip was created using *iVisit-Communicate* that (1) allowed students to virtually visit the mechanical room of a commercial building facility; and (2) provided conversational opportunities for students to communicate with a virtual mechanical system professional. This section will describe the development of this site visit case study and its learning and assessment modules.

Guided Scenario: A Learning Module

A virtual mechanical system professional guiding students on a virtual field trip to the mechanical room of a commercial building facility was created to cover the main learning objectives of the targeted field trip. In this scenario, students can intensively practice their active listening skills. This targeted field trip had the following learning objectives:

- *Learning Objective 1:* Understand the function of essential devices (including air handling unit and energy recovery ventilation) and the airflow movement in the HVAC (heating, ventilation, and air conditioning) system.
- *Learning Objective 2:* Understand the function of essential devices (including the heat exchanger and pumps) and the water flow movement in the plumbing system.
- *Learning Objective 3:* Be able to interpret mechanical drawings.

Leaning contents in the guided scenarios were created accordingly. Several 360-degree panoramas were captured in a mechanical room of a commercial building, and considering the previous learning objectives, a few were selected for the guided scenarios. Two panoramas were specifically selected to cover essential devices and ductwork in the HVAC system, and the other two to cover essential devices and pipes in the plumbing system.

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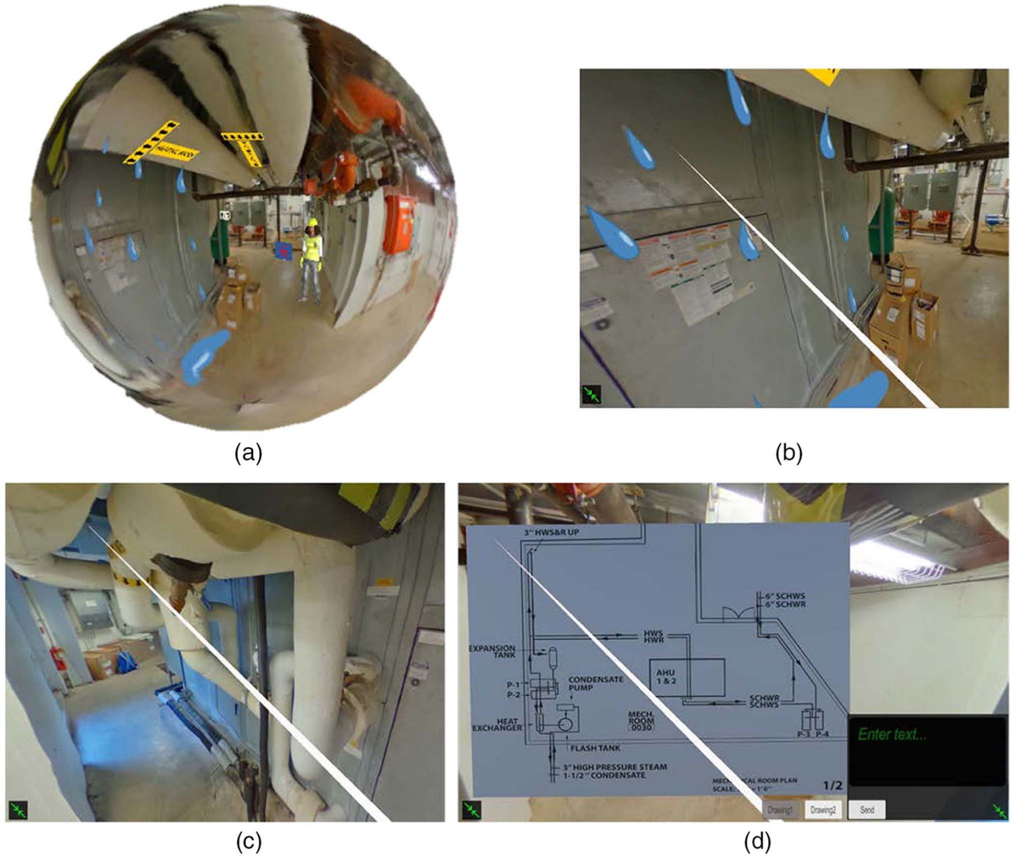

Fig. 3. *iVisit-Communicate* conversational scenario: (a) the conversational scenario; (b) a screenshot of the leaking pipe; (c) connections between the pipe and other equipment; and (d) embedded drawings in the scenario.

The guided scenarios follow a linear heating and sequential guided trip structure, which simulates a real-world field trip. The virtual human serves as a mechanical systems professional who guides the trip and introduces the spatiotemporal context of the mechanical room by guiding the students through different hotspots on the site and discussing specific information at those relevant hotspots. For example, in one of the guided scenarios, the virtual human explains how the pipes and equipment in the plumbing system are connected and placed. The virtual mechanical systems professional first stands next to a high-pressure steam pipe, which is the start of the hot water circulation in the building while discussing the relevant content, which is also augmented on the scene to facilitate students' understanding of the pipe placement and water flows. Once students complete this hotspot, they can continue to the next ones (e.g., heat exchanger, hot water distribution). After completing all the hotspots, students can either repeat the visit to any of those hotspots to reinforce the learning or move to the following guided scenario. The same procedure has been used for all the hotspots in the guided scenarios.

Conversational Scenario: A Learning Assessment Module

Then the conversational scenario was created, which provided a two-way communication that simulates interactive conversations between students and the virtual human (i.e., mechanical system professional) on the jobsite. In this scenario, students can practice active listening and written communication skills. The main goal of this communication opportunity was for the students to use the knowledge gained from the previous guided scenario to discuss and solve a real-world problem about mechanical systems through conversations with the virtual human in the mechanical room. The conversational scenario [Fig. 3(a)] was designed based on the contents covered in the guided scenarios. Students were asked to locate a leaking water pipe [Fig. 3(b)] by navigating the virtual environment and then identifying the function and diameter of that leaking pipe. This required students to focus on the connections between the pipe and other equipment [Fig. 3(c)] and review the related drawings [Fig. 3(d)]. More specifically, students were required to investigate (1) if the pipe is in a hot or chilled water system, (2) if the pipe is in a supply or return water system, and (3) the diameter of the pipe. The virtual human could provide feedback and hints based on students' specific input at different steps during the problem-solving scenario.

In the VH condition, the virtual human introduced herself and the general context at the beginning of this scenario. To train students to start the two-way communication in *iVisit-Communicate*, all students were prompted to ask the virtual human the first question of, *Tell me about the task*, to learn about the real-world problem. Then students had complete control of the order, content, and phrasing style of the questions or statements they made to the virtual human. If the student's finding was correct, the virtual human would agree with the student and then ask for other information. Here is an example of such a conversation:

(Student): "Is the pipe part of the heating water system?"

(Virtual Human): "Good observation! I believe you are on the right track. Please also let me know if this is a supply or a return pipe."

(Student): "This is a supply pipe."

(Virtual Human): "Great job! One last thing, what is the diameter of this leaking pipe?"

(Student): "I believe the diameter is 5 inches."

(Virtual Human): "That's perfect! I believe I have enough information to document the leaking pipe and order pipes. You did an excellent job! Please feel free to leave this platform whenever you want."

If the student's finding was not on the right track, then the virtual human would provide some hints or follow-up questions to help the student refine his/her findings. Here is an example of such a conversation:

(Student): "Is this a hot water return pipe?"

(Virtual Human): "I would suggest you observe the orientation of the arrows on the yellow marker. If it's pointing to the AHU, this pipe should be supplying water. On the contrary, if it's pointing to the water pump, this pipe is in a return system."

A similar approach is applied in other problem-solving processes of this mechanical systems field trip. This conversational corpus integrated with logical programming simulates a natural two-way communication process where two parties exchange information and feedback constantly.

In the No-VH condition, students were directly introduced to the general context and the real-world problem without the virtual human presence. The real-world problem and the provided information were the same for both conditions. Since there was no two-way communication integrated into this condition, students could take as much time and attempts as they needed to solve the task. And finally, their task results were collected after they decided they had solved the assigned task and left the scenario.

Table 1. Student demographics by experimental condition

Variable	Category	Frequency (Percentage) No-VH	VH
Gender	Male	11 (65%)	10 (59%)
	Female	6 (35%)	7 (41%)
Work experience	None	2 (12%)	2 (12%)
	Less than 1 year	10 (59%)	9 (53%)
	1–2 years	1 (6%)	4 (23%)
	More than 2 years	4 (23%)	2 (12%)
Understanding of 360-degree panoramic images	None	2 (12%)	2 (12%)
	Some knowledge of	9 (53%)	6 (35%)
	Fair	6 (35%)	7 (41%)
	Competent	0 (0%)	2 (12%)
Understanding of virtual reality	None	0 (0%)	0 (0%)
	Some knowledge of	10 (59%)	7 (41%)
	Fair	7 (41%)	9 (53%)
	Competent	0 (0%)	1 (6%)
Understanding of HAVC systems	None	1 (6%)	0 (0%)
	Some knowledge of	8 (47%)	11 (65%)
	Fair	8 (47%)	5 (29%)
	Competent	0 (0%)	1 (6%)
Understanding of plumbing systems	None	4 (24%)	2 (12%)
	Some knowledge of	6 (35%)	9 (53%)
	Fair	7 (41%)	5 (29%)
	Competent	0 (0%)	1 (6%)

Experiment Results and Discussions

Students from the BCN4510C Mechanical Systems course at the University of Florida were recruited and randomly assigned to each condition. Thirty-four students were recruited and randomly assigned to the two conditions (Table 1). Students had an average age of 23 years old, and the majority in both groups were males (No-VH: 65%, VH: 59%). More than half of the students under each condition had less than one year of working experience (No-VH: 59%, VH: 53%). The majority of the students in both conditions had some to fair understanding of 360-degree panoramic images (No-VH: 88%, VH: 76%), virtual reality (No-VH: 100%, VH: 94%), HAVC systems (No-VH: 94%, VH: 94%) and plumbing systems (No-VH: 76%, VH: 82%). Overall, students in both conditions had a very similar knowledge background.

For RQ #1: How does *iVisit-Communicate* facilitate students' communication practices in a problem-based learning scenario? This study collected two measurements to subjectively and objectively understand this question. On the one hand, students' communication practices were directly evaluated by communication skills questions in a subjective manner. In addition, an open-ended question was also asked to collect qualitative data. On the other hand, students' communication practices are indirectly assessed by the communication outcome—students' task performance—to objectively understand how *iVisit-Communicate* facilitates the communication practice, which can be reflected by better task performance.

Communicate Skills (for VH Condition only)

Students (in the VH condition only) subjectively evaluated their communication skills practice using the STEM Interpersonal Communication Skills Assessment Battery (Table 2; Wilkins et al. 2015). Overall, students' high level of satisfaction with the two-way communication component was explicitly expressed. For example, a student commented that *the ability to ask questions and have the professional answer them is very impressive*. To be more specific, students demonstrated somewhat to strongly agree with all of the statements, suggesting *iVisit-Communicate* allowed them to practice communication skills from multiple aspects, including phrasing questions, receiving and processing feedback, and asking for clarifications. Students' comments also indicated how *iVisit-Communicate* enabled them to practice their communication skills. For example, a student mentioned that the virtual human would *hint at where you need to look if you get the question wrong, essentially forcing critical thinking*. This reflected that *iVisit-Communicate* successfully provided students opportunities to practice interpreting feedback they have received (statement #15) and recognizing the main underlying point of a speaker's message (statement #20). Another student commented that *as long as you phrase your questions directly, the guide is very helpful*. On the one hand, this suggested *iVisit-Communicate* required students to focus on planning a well-crafted message (statement #2), staying focused on their needs while expressing themselves (statement #17), and expressing their views in a way that would improve the likelihood of getting their desired outcome (statement #3). However, on the other hand, this comment aligned with a finding from a previous study, where the researchers investigated the difference between communicating with a real and virtual human. It was found that communicating with the virtual human was less sincere, as participants tend to communicate with the virtual human in a rapid-fire fashion (i.e., using choppy sentences and direct questions) (Raij et al. 2007). A similar observation was made in this study, where some students tend to use direct questions. This was due to the virtual human's limited expressiveness (e.g., vocal and facial expressions) and the difficulty with context-dependent questions and other conversational idiosyncrasies (Raij et al. 2007).

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Table 2. Students' subjective assessments on communication skills practice (VH group only)

Communication skills statements	Descriptive analysis	
The interaction with the virtual human helped me practice my communication skills where I can ...	Mean	SD
1. Check the accuracy of my interpretation	4.53	0.50
2. Plan a well-crafted message	4.65	0.48
3. Express my views in a way that would improve the likelihood of getting my desired outcome	4.24	0.81
4. Use past experiences as a way to measure the feedback received	4.00	1.08
5. Present myself in the manner in which I want to be perceived	4.35	0.68
6. Behave in a manner that facilitates good interpersonal communication	4.29	0.67
7. Identify the objective of my message	4.35	0.48
8. Check to ensure that I have understood the speaker's point of view	4.53	0.61
9. Identify the desired outcome(s) of my communication interaction	4.76	0.42
10. Focus my attention on the feedback being received	4.59	0.60
11. Assess if the feedback received fits with my perception	4.53	0.61
12. Ask for clarification when I am unsure about the feedback received	4.71	0.46
13. Use the feedback received as a learning tool	4.65	0.59
14. Acknowledge feedback while expressing my views confidently	4.53	0.70
15. Interpret feedback I have received	4.59	0.69
16. Express my personal needs while still conveying professionalism	4.24	0.88
17. Stay focused on my needs while expressing myself	4.29	0.89
18. Be consistent in what I am saying and how am saying it	4.47	0.85
19. Consider my intentions for communicating a certain message	4.41	0.84
20. Recognize the main underlying point of a speaker's message	4.59	0.60

Based on students' quantitative and qualitative evaluations of the two-way communication component, it was found that *iVisit-Communicate* features natural conversations and underlying hints that stimulate the critical thinking of students during communication. Furthermore, *iVisit-Communicate* enabled students to refine their findings based on virtual human feedback and clarify or modify their responses accordingly. This approach simulated a progressing conversation where students constantly communicate with other professionals and experts on site, change their plans and approaches accordingly, and ultimately reach a mutual understanding with other parties.

Task Performance

Task performance was evaluated considering the time spent to complete the task and the accuracy of the task (Table 3). Mann-Whitney U test was conducted in this study as the measured data are not normally distributed (Nachar 2008). For the task time, it took students in the VH condition (4 min:56 s) significantly less time than the No-VH condition (8 min:22 s) to complete the task. In the VH group, where the communication component was integrated, students had the opportunity to listen to VH's statements, explain their key findings back to the VH, and ask for clarification and feedback. Clearly, this two-way communication opportunity with the VH has significantly reduced the time required to complete the task.

For the accuracy of the task, students had a significantly higher score in the VH condition (100%) compared with the No-VH condition (80.33%). Notably, the VH condition researched a 100% correct response rate in the task. In the VH condition, students could have interacted with the virtual human and revised their findings based on some feedback or hints they would get from the VH. Specifically, all students of VH condition successfully identified the function of the pipe (chilled or hot water system) on their first attempt. For a bit harder questions, 82% of VH condition students successfully identified the function of the pipe (supply or return system) at their first attempt and only 41% of them successfully identified the diameter of the pipe at their first attempt. But after interacting with the virtual human and using the feedback and hints provided, they all were able to get to 100% accuracy (in their second or third attempts). Such specific-to-task scaffolding capability provided by the VH was also supported by students' qualitative feedback. For example, one student indicated that *I liked the bot hints at where you need to look if you get the question wrong, essentially forcing critical thinking from students, making it so you can't just click through activities*.

Table 3. Skill assessment performance by experimental conditions

Variables	Mean (SD)		Mann-Whitney U	
	No-VH	VH	Statistic	p-value
Task time (Min: Sec)	8:22 (4:29)	4:56 (2:36)	75	0.016[a]
Task score	80.33% (20.67%)	100% (0)	221	0.008[a]

[a]Indicates a significant difference between the conditions (p-value < 0.05).

For RQ #2: How does the two-way communication component enabled by *iVisit-Communicate* affect students' learning experience in the virtual field trip? This study collected three measurements that reflect students' learning experience in the virtual space: task load index, sense-of-presence, and system usability. Mann-Whitney U test was conducted in this study for these three measurements as they have an ordinal type and are not normally distributed (Nachar 2008).

Task Load Index

Students in both conditions provided similar ratings for almost all six aspects of the task load index, and none of the differences were statistically significant (Table 4). The workload score was further calculated to map to a hundred-point scale, which can be between 0 (low) and 100 (high) (Grier 2015; Sauro 2019). The average workload score for students in the No-VH condition (43.13) was slightly higher than students in the VH condition (39.61); however, the difference was not significant. Since there are no normalized interpretations of what is an acceptable or unacceptable workload, other researchers conducted meta-analyses to examine workload scores from 1,173 studies (Hart 2006; Sauro 2019). Considering the outcomes of those studies, *iVisit-Communicate* presented below

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Table 4. *iVisit-Communicate* task load index results

Task load index	Scale	Mean (SD)		Mann-Whitney U	
		No-VH	VH	Statistic	p-value
1. Mental demand: How mentally demanding was the task?	1 Very Low–5 Very High	3.00 (0.52)	2.41 (0.24)	132	0.901
2. Physical demand: How physically demanding was the task?	1 Very Low–5 Very High	1.50 (0.20)	1.59 (0.23)	141.5	0.845
3. Temporal demand: How hurried or rushed was the pace of the task?	1 Very Low–5 Very High	1.88 (0.22)	1.71 (0.24)	116	0.488
4. Performance: How successful were you in accomplishing what you were asked to do?	1 Perfect–5 Failure	2.13 (0.26)	2.06 (0.29)	126	0.736
5. Effort: How hard did you have to work to accomplish your level of performance?	1 Very Low–5 Very High	2.63 (0.20)	2.41 (0.21)	115.5	0.465
6. Frustration: How insecure, discouraged, imitated, stressed, and annoyed were you?	1 Very Low–5 Very High	1.81 (0.26)	1.71 (0.19)	135	0.986
	TLX score	43.13 (12.73)	39.61 (13.79)	108.5	0.326

Table 5. *iVisit-Communicate* sense-of-presence results

Statements	Likert scale	Mean (SD)		Mann-Whitney U	
		No-VH	VH	Statistic	p-value
1. Please rate your sense of being on the construction jobsite	Not at all 1–5 Very much	4.53 (1.29)	3.82 (0.62)	41.5	0.000
2. To what extent were there times during the experience when the construction jobsite was the reality for you?	At no time 1–5 Almost all the time	3.53 (0.92)	3.41 (1.03)	145	1.000
3. When you think back about your experience, do you think of the construction jobsite more as images that you saw, or more as somewhere that you visited?	Image as I saw 1–5 Somewhere that I visited	3.53 (1.19)	3.47 (1.38)	144.5	1.000
4. During the time of the experience, which was strongest on the whole, your sense of being on the construction jobsite or elsewhere?	Being elsewhere 1–5 Being on the jobsite	3.76 (0.94)	3.88 (1.08)	158	0.658
5. During the time of the experience, did you often think to yourself that you were actually on the construction jobsite?	Not very often 1–5 Very much so	3.12 (1.08)	3.41 (1.33)	168.5	0.413

midpoint workload scores in both No-VH and VH conditions. This suggested a relatively low workload requirement was observed in *iVisit-Communicate*.

Specifically, students in the No-VH condition found the task required a moderate level of mental demand (3.00), while a lowered level of mental demand was rated by students in the VH condition (2.41). This slight difference could be due to the accessibility to the virtual human's feedback and hints. Students in VH condition were able to request feedback from the virtual human to reduce confusion and this might have lowered their mental demands. As students indicated in the qualitative feedback, while students in both conditions encountered some difficulties, students in the VH condition could ultimately be led to *the final answer* after they *typed responses and the virtual human asked for more specifics*.

The remaining aspects were rated very similarly. The students in both conditions found the task required very low physical demand (No-VH: 1.50, VH: 1.59) and also felt a very low amount of rush (No-VH: 1.88, VH: 1.71) or frustration (No-VH: 1.81, VH: 1.71) when they worked on the task. They also thought that they were somewhat successful in accomplishing the assigned task (No-VH: 2.13, VH: 2.06) while working with a moderate level of effort (No-VH: 2.63, VH: 2.41).

Sense-of-Presence

Table 5 shows the descriptive analysis and statistical test results for the two groups' sense-of-presence results. The average sense-of-presence scores (No-VH: 3.69, VH: 3.60) suggest a moderate level of sense-of-presence was supported by *iVisit-Communicate*. There was no significant difference found between the two groups in terms of the overall sense-of-presence.

More specifically, students had a somewhat high sense of being there on the construction jobsite (No-VH: 4.53, VH: 3.82) and thought that they had a stronger sense of being on the jobsite than elsewhere (No-VH: 3.76, VH: 3.88). These ratings aligned with multiple students' comments: *(iVisit-Communicate) was a very accurate representation of reality* and *I could look around the site effortlessly*. They moderately believed the construction jobsite was the reality to them (No-VH: 3.53, VH: 3.41) and it was more like somewhere they visited instead of images they saw (No-VH: 3.53, VH: 3.47). During the virtual field trip experience, students provided a neutral feeling about often thinking of themselves as actually being on the construction jobsite (No-VH: 3.69, VH: 3.60). Particularly, statement #1 was the only one that presented a statistically significant difference between the two conditions, where students in the No-VH condition (4.53) agreed significantly more than the VH condition (3.82) that they sensed being on the jobsite. The lower rating in the VH group may be due to the resolution difference between the virtual human and the panoramic environment. A previous study found that sense-of-presence can be negatively affected by the contrast between the panoramic environment captured from reality and a virtual character modeled by the computer with a higher resolution (Wen and Gheisari 2021).

The overall moderate level of sense-of-presence may be explained for two reasons. First, as multiple students indicated, *the picture quality needs to be improved* as *some of them are slightly blurry*. This may be partially due to limited 360 camera specifications and also panoramas' quality reduction by the game engine

Table 6. *iVisit-Communicate* system usability result

System usability statements	Mean (SD)		Mann-Whitney U	
	No-VH	VH	Statistic	p-value
1. I think that I would like to use the *iVisit-Communicate* system frequently	3.82 (0.86)	3.88 (1.08)	155.5	0.708
2. I found the *iVisit-Communicate* system unnecessarily complex	2.12 (0.96)	2.35 (1.08)	160	0.610
3. I thought the *iVisit-Communicate* system was easy to use	4.29 (0.75)	4.24 (0.42)	130	0.634
4. I think that I would need the support of a technical person to be able to use the *iVisit-Communicate* system	2.41 (1.33)	2.29 (1.36)	136.5	0.786
5. I found the various functions in the *iVisit-Communicate* system well-integrated	4.00 (0.69)	4.35 (0.59)	182	0.205
6. I thought there was too much inconsistency in the *iVisit-Communicate* system	2.06 (0.87)	1.94 (1.00)	129	0.610
7. I would imagine that most people would learn to use the *iVisit-Communicate* system very quickly	4.29 (0.89)	4.18 (0.71)	125	0.518
8. I found the *iVisit-Communicate* system very cumbersome to use	2.65 (1.23)	2.71 (1.13)	152	0.812
9. I felt very confident in using the *iVisit-Communicate* system	4.06 (0.64)	4.00 (0.91)	144	1.000
10. I needed to learn a lot of things before I could get going with *iVisit-Communicate system*	2.18 (1.10)	2.12 (1.02)	140.5	0.892

Unity (Wen and Gheisari 2021). Therefore, increasing the quality of the 360-degree panoramas and improving the quality of the shader in the game engine could help to increase students' feelings of being on the construction jobsite. Second, how the camera is placed also affects how students feel about being on the jobsite. From one student's comment, it was found that though *the images were definitely of good quality*, still at some point he/she *didn't feel completely immersed in the jobsite, because the camera is placed so close to a wall or a large vertical element*. This brings a valuable point when 360-images are used to create an immersive environment: the camera should be placed in a proper location and at a proper height that appropriately represents the users' eye level. Placing the camera at a too tall or short height, too close to a vertical structure, or in a too narrow area may result in a less natural, realistic, and immersive feeling. If there is a need to capture some details in a place that is too high or narrow in the environment, instead of directly placing the camera at that location, augmenting the details on top of the 360-image captured at a natural position may be a better alternative.

System Usability

The SUS (system usability score) was calculated for No-VH (72.65) and VH (73.09) groups as the composite measure of the overall system usability (Brooke 1996). Conventionally a system obtaining a SUS score larger than 68 is with above-average usability; therefore, *iVisit-Communicate* is considered a decently usable system for both conditions. The descriptive analysis shows that students demonstrated a relatively high level of agreement on several statements (Table 6). These high agreement scores indicate that the students believed they would like to use the system frequently (No-VH: 3.82, VH: 3.88), the *iVisit-Communicate* was easy to use (No-VH: 4.29, VH: 4.24) and well-integrated (No-VH: 4.00, VH: 4.35), most people would learn to use it very quickly (No-VH: 4.29, VH: 4.18), and they are confident in using it (No-VH: 4.06, VH: 4.00). Students' comments suggested *iVisit-Communicate* was an *easy and fun* experience as it *was extremely user friendly and the virtual assistant provides clear instructions that help understand the process*, which further explained students' positive ratings for these aspects of system usability.

Meanwhile, students disagreed that *iVisit-Communicate* was unnecessarily complex (No-VH: 2.12, VH: 2.35) or inconsistent (No-VH: 2.06, VH: 1.94). As a student stated, *once you understand (iVisit-Communicate) after one or two short parts, it is the same thing throughout the experience*. Students didn't believe they need the support of a technical person (No-VH: 2.41, VH: 2.29) or to learn a lot of things (No-VH: 2.18, VH: 2.12) to be able to use *iVisit-Communicate*, as it *was pretty intuitive and I (the student) did not have issues navigating it*. Students also slightly disagreed that the *iVisit-Communicate* system was very cumbersome to use (No-VH: 2.65, VH: 2.71). Given the overall positive comments provided by students, the almost-neutral rating on this aspect would not be considered problematic. Nevertheless, there are some potential improvements to further increase the system usability. Though the features of the system (e.g., clipboard and input question box) were introduced and demonstrated at the beginning of the experience, several students were still *somewhat lost at the beginning (of the guided scenario)* and needed *a short period (of time) to understand (the system)*. It was recommended to add a demonstration video to intuitively display the system mechanism and the available interactive features to better prepare students for *iVisit-Communicate*.

Conclusion

This study proposed using virtual humans in a 360-degree virtual field trip for students to practice communication skills within complex spatiotemporal contexts. *iVisit-Communicate* provided a field trip experience that supported an intelligent communication system where students could gain information and communicate with a virtual professional to reinforce and apply the knowledge they learned during the field trip. This approach could supplement the common training methods in the traditional classroom or field trip setting by enabling students to practice communication skills within the situated context of real-world jobsites. The outcome of this study also aids educators in AEC-relevant educational programs in better understanding the importance and potential of implementing communication components during virtual field trips. Specifically, this study investigated how *iVisit-Communicate* facilitated students' communication practices in virtual field trips (RQ #1) and how the two-way communication component affects their learning experience in such virtual environments (RQ #2). This paper advanced the understanding of the feasibility, benefits, and limitations of applying virtual humans as communication partners for students within virtual field trips.

To create the *iVisit-Communicate* system, the learning objectives for the virtual trip needed to be determined first. Based on those objectives, the narratives for one-way communication (i.e., guided scenario) and two-way communication (i.e., conversational scenario) were created. Meanwhile, 360-degree scenes were captured to supplement the narrative and provide a situated visual environment for the field trip. The conversational corpus for two-way communication was also developed and improved iteratively. Then, the 360-degree panoramic environments were integrated, and the virtual professional was embedded in the virtual environment. Finally, a between-subject experiment based on a problem-solving activity was conducted, and several measures such as communication skill, task performance, system usability, and sense-of-presence were assessed.

RQ #1 was investigated by analyzing the communication skills questions and task performance. It was revealed that *iVisit-Communicate* facilitated communication by allowing students to practice several skills, including planning a well-crafted message, staying focused on their needs while expressing themselves and expressing their views in a way that would improve the likelihood of getting their desired outcome. As an indirect indicator of the communication practices, the task performance was significantly better in the VH condition, suggesting that *iVisit-Communicate* successfully facilitated students' communication practices. Specifically, the results showed that two-way communication significantly improved task performance in terms of accuracy and time. It revealed the significance of implanting the communication component in the virtual field trip. It can provide students with not only significant facilitation to complete the task, but also the communication opportunity to listen to the virtual human, interact with her, and ask for clarification and feedback if needed. Additionally, students provided very positive feedback on this system and found this virtual field trip integrated with communication a *challenging, impressive and fun* learning experience. To answer RQ #2, the task load index, sense-of-presence, and system usability collected from both conditions were examined using Mann-Whitney U tests. No statistically significant difference was detected in any aspect of students learning experience in the virtual environment, which suggests the two-way communication component does not affect students learning experience in these three aspects. Therefore, these three aspects are discussed for both conditions without differentiation. In terms of system usability, *iVisit-Communicate* was rated as a usable and easy-to-use system. Students' quantitative ratings and comments were mostly positive; however, adding a demonstration video to display the system features intuitively may further improve the system usability. Furthermore, students' ratings revealed a moderate level of sense-of-presence in *iVisit-Communicate*. This limited sense-of-presence may be due to (1) the limited quality of 360 panoramas; and (2) the improper camera placement. While the first reason can be difficult to avoid due to the restrictions of camera specifications and the game engines' internal process, the second reason can be easily avoided. It is highly recommended that the camera should be placed in a proper location and at a proper height that appropriately represents the users' eye level.

Last but not least, there are several study limitations. First, the communication scope was limited to just one problem-solving task in a mechanical systems course, and the sample size under each condition was also small. Given this fact, the pool of the collected communication data was very small, limiting the potential of further content analysis for the recorded communication. To better understand the potential of *iVisit-Communicate*, the problem context and focus should be expanded to other areas of construction, and the sample size should also be expanded. With a larger pool of communication data, a deeper investigation may be conducted on the communication data to investigate if certain types of messages, keywords, and verbal cues may have had an impact on the effectiveness of VH. More specifically, the expansion of the communication scope would make it computationally challenging and data-intensive to create, so future studies might require investigating other methods (e.g., artificial intelligence, semi-intelligent systems) to create and improve the growing conversational corpus to support such a system. Second, a lack of genuineness during the two-way communication was observed in this study, resulting from the virtual human's lack of vivid vocal and facial expressions. In this study, computer-generated audio and characters—instead of real human voices or videos—were applied as they were cost-effective for the iterative improvements and refinements of the learning contents and the conversational corpus. In future studies that are associated with the simulated communication process, researchers should carefully consider the trade-offs between applying computer-generated or real-human-generated medium.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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References

Adedokun, O. A., K. Hetzel, L. C. Parker, J. Loizzo, W. D. Burgess, and J. Paul Robinson. 2012. "Using virtual field trips to connect students with university scientists: Core elements and evaluation of zipTripsTM." *J. Sci. Educ. Technol.* 21 (5): 607–618. https://doi.org/10.1007/s10956-011-9350-z.

Anderson, A., C. S. Dossick, R. Azari, J. E. Taylor, T. Hartmann, and A. Mahalingham. 2014. "Exploring BIMs as avatars: Using 3D virtual worlds to improve collaboration with models." In *Proc., Construction Research Congress 2014: Construction in a Global*, 179–188. Reston, VA: ASCE.

Anderson, A., C. S. Dossick, J. Iorio, and J. E. Taylor. 2017. "The impact of avatars, social norms and copresence on the collaboration effectiveness of AEC virtual teams." *J. Inf. Technol. Constr.* 22 (May): 287–304.

Arslan, G. 2004. "Design of a web-based virtual construction site visit for education of civil engineering student (Part I)." In *Towards a vision for information technology in civil engineering*. 1–8. Reston, VA: ASCE.

Badler, N. 1997. "Virtual humans for animation, ergonomics, and simulation." In *Proc., IEEE Nonrigid and Articulated Motion Workshop*, 28–36. New York: IEEE.

Bangor, A., P. Kortum, and J. Miller. 2009. "Determining what individual SUS scores mean: Adding an adjective rating scale." *J. Usability Stud.* 4 (3): 114–123.

Brooke, J. 1996. "SUS: A "quick and dirty'usability." In *Usability evaluation in industry*, 189. London: CRC Press.

Capon, N., and D. Kuhn. 2004. "What's so good about problem-based learning?" *Cognit. Instr.* 22 (1): 61–79. https://doi.org/10.1207/s1532690Xci2201_3.

Cendan, J., and B. Lok. 2012. "The use of virtual patients in medical school curricula." In *Advances in physiology education*. Bethesda, MD: American Physiological Society.

Chen, H. n.d. "A brief introduction to chatbots with dialogflow." Accessed December 8, 2021. https://www.margo-group.com/en/news/a-brief-introduction-to-chatbots-with-dialogflow/.

Cheng, J., K. Chen, W. Chen, and C. Li. 2018. "A location aware augmented reality collaborative system framework for facility maintenance management." In *Proc., 18th Int. Conf. on Construction Applications of Virtual Reality (CONVR2018)*, 30–39. Auckland, New Zealand: Univ. of Auckland.

Clement, A., and T. Murugavel. 2015. "English for employability: A case study of the English language training need analysis for engineering students in India." *English Language Teach.* 8 (2): 116. https://doi.org/10.5539/elt.v8n2p116.

Dossick, C. S., A. Anderson, R. Azari, J. Iorio, G. Neff, and J. E. Taylor. 2015. “Messy talk in virtual teams: Achieving knowledge synthesis through shared visualizations.” *J. Manage. Eng.* 31 (1): A4014003. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000301.

Du, J., Y. Shi, C. Mei, J. Quarles, and W. Yan. 2016. “Communication by interaction: A multiplayer VR environment for building walkthroughs.” In *Proc., Construction Research Congress 2016*, 2281–2290. Reston, VA: ASCE.

Eiris, R., and M. Gheisari. 2017. “Research trends of virtual human applications in architecture, engineering and construction.” *J. Inf. Technol. Constr.* 22 (9): 168–184.

Eiris, R., J. Wen, and M. Gheisari. 2020. “iVisit: Digital interactive construction site visits using 360-degree panoramas and virtual humans.” In *Proc., ASCE Construction Research Congress*. London: CRC Press.

Eiris, R., J. Wen, and M. Gheisari. 2021. “iVisit–Practicing problem-solving in 360-degree panoramic site visits led by virtual humans.” *Autom. Constr.* 128 (Aug): 103754. https://doi.org/10.1016/j.autcon.2021.103754.

Eiris, R., J. Wen, and M. Gheisari. 2022. “iVisit-collaborate: Collaborative problem-solving in multiuser 360-degree panoramic site visits.” *Comput. Educ.* 177 (6): 104365. https://doi.org/10.1016/j.compedu.2021.104365.

Eiris Pereira, R., and M. Gheisari. 2017. “Site visit application in construction education: A descriptive study of faculty members.” *Int. J. Constr. Educ. Res.* 15 (2): 1–17. https://doi.org/10.1080/15578771.2017.1375050.

Fenner, S. 2021a. “One-way communication: Definition, advantages & examples—Video & lesson transcript.” Accessed April 14, 2022. https://study.com/academy/lesson/one-way-communication-definition-advantages-examples.html.

Fenner, S. 2021b. “What is two-way communication?—Definition, systems & examples—Video & lesson transcript.” Accessed April 14, 2022. https://study.com/academy/lesson/what-is-two-way-communication-definition-systems-examples.html.

Finch, E., and R. D. Wing. 1996. “A navigable walkthrough simulator for built environment education: Archiwalk.” In *Facilities*. Bradford, UK: MCB University Press.

Fischer, F., S. Helmer, A. Rogge, J. I. Arraras, A. Buchholz, A. Hannawa, and M. Horneber. 2019. “Outcomes and outcome measures used in evaluation of communication training in oncology—A systematic literature review, an expert workshop, and recommendations for future research.” *BMC Cancer* 19 (1): 808. https://doi.org/10.1186/s12885-019-6022-5.

Goedert, J., Y. Cho, M. Subramaniam, H. Guo, and L. Xiao. 2011. “A framework for virtual interactive construction education (VICE).” *Autom. Constr.* 20 (1): 76–87. https://doi.org/10.1016/j.autcon.2010.07.002.

Grier, R. A. 2015. “How high is high? A meta-analysis of NASA-TLX global workload scores.” In *Proc., Human Factors and Ergonomics Society Annual Meeting*, 1727–1731. Thousand Oaks, CA: SAGE.

Hart, S. G. 2006. “Nasa-task load index (NASA-TLX); 20 years later.” In *Proc., Human Factors and Ergonomics Society Annual Meeting*, 904–908. Thousand Oaks, CA: SAGE.

Higuera-Trujillo, J. L., J. L. T. Maldonado, and C. L. Millán. 2017. “Psychological and physiological human responses to simulated and real environments: A comparison between Photographs, 360 Panoramas, and Virtual Reality.” *Appl. Ergon.* 65 (Nov): 398–409. https://doi.org/10.1016/j.apergo.2017.05.006.

IBM. 2021. “Watson—Text to speech.” Accessed April 15, 2022. https://www.ibm.com/cloud/watson-text-to-speech.

Jaselskis, E., J. Ruwanpura, T. Becker, L. Silva, P. Jewell, and E. Floyd. 2011. “Innovation in construction engineering education using two applications of internet-based information technology to provide real-time project observations.” *J. Constr. Eng. Manage.* 137 (10): 829–835. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000297.

Landorf, C., G. Brewer, K. Maund, and S. Ward. 2015. “Onsite and online: A 4-dimensional multi-disciplinary learning environment for construction industry professionals.” In *Living and learning: Research for a better built environment, faculty of architecture, building and planning*. 987–996. Melbourne, VIC, Australia: Univ. of Melbourne.

Lees, H. E., and N. Noddings. 2016. *The Palgrave international handbook of alternative education*. Berlin: Springer.

Littlejohn, S., and K. Foss. 2009. “Nonverbal communication theories.” In *Encyclopedia of communication theory*, 691–694. Thousand Oaks, CA: SAGE.

Lok, B. 2006. “Teaching communication skills with virtual humans.” In *IEEE computer graphics and applications*. New York: IEEE.

Maghool, S. A. H., S. H. I. Moeini, and Y. Arefazar. 2018. “An educational application based on virtual reality technology for learning architectural details: Challenges and benefits.” *Int. J. Archit. Res.* 12 (3): 246.

Mei, Q., and R. Wing. 1999. “Robotic 360/spl deg/photography for virtual site visits.” In *Proc., 1999 IEEE Int. Conf. on Information Visualization*, 214–219. New York: IEEE.

Mokhtar, A. H. M. 2019. *BIM as a pedagogical tool for teaching HVAC systems to architecture students*, 123–133. Reston, VA: ASCE.

Murray, M., and S. Tennant. 2016. “‘Off-piste pedagogy’: Construction site visits for undergraduate civil engineers.” In *Proc., 6th Int. Symp. of Engineering Education*, 165–172. London: Univ. of Manchester.

Nachar, N. 2008. “The Mann-Whitney U: A test for assessing whether two independent samples come from the same distribution.” *Tutorials Quant. Methods Psychol.* 4 (1): 13–20. https://doi.org/10.20982/tqmp.04.1.p013.

National Aeronautics and Space Administration. 2020. “TLX @ NASA Ames—Home.” Accessed August 24, 2022. https://humansystems.arc.nasa.gov/groups/TLX/.

Pham, H. C., N.-N. Dao, J.-U. Kim, S. Cho, and C.-S. Park. 2018. “Energy-efficient learning system using web-based panoramic virtual photoreality for interactive construction safety education.” *Sustainability* 10 (7): 2262. https://doi.org/10.3390/su10072262.

Ragan, E. D., A. Sowndararajan, R. Kopper, and D. A. Bowman. 2010. “The effects of higher levels of immersion on procedure memorization performance and implications for educational virtual environments.” *Presence: Teleoperators Virtual Environ.* 19 (6): 527–543. https://doi.org/10.1162/pres_a_00016.

Raij, A. B., K. Johnsen, R. F. Dickerson, B. C. Lok, M. S. Cohen, M. Duerson, and R. R. Pauly. 2007. “Comparing interpersonal interactions with a virtual human to those with a real human.” *IEEE Trans. Visual Comput. Graphics* 13 (3): 443–457. https://doi.org/10.1109/TVCG.2007.1030.

Rossen, B., S. Lind, and B. Lok. 2009. “Human-centered distributed conversational modeling: Efficient modeling of robust virtual human conversations.” In *Proc., Int. Workshop on Intelligent Virtual Agents*, 474–481. Berlin: Springer.

Rubin, R. B., and M. M. Martin. 1994. “Development of a measure of interpersonal communication competence.” *Commun. Res. Rep.* 11 (1): 33–44. https://doi.org/10.1080/08824099409359938.

Sauro, J. 2019. “10 things to know about the NASA TLX—MeasuringU.” Accessed August 25, 2022. https://measuringu.com/nasa-tlx/.

Sharma, P. 2022. “Written communication: Meaning, advantages and limitations.” Accessed November 8, 2022. https://www.yourarticlelibrary.com/business-communication/written-communication/written-communication-meaning-advantages-and-limitations/70195.

Sheth, T. D. 2015. “Communication skill: A prerequisite for engineers.” *Int. J. Stud. English Language Lit.* 3 (7): 51–54.

Shi, Y., J. Du, S. Lavy, and D. Zhao. 2016. “A multiuser shared virtual environment for facility management.” *Procedia Eng.*, 145 (Jan): 120–127. https://doi.org/10.1016/j.proeng.2016.04.029.

SkillsYouNeed. 2022. “Active listening | SkillsYouNeed.” Accessed November 8, 2022. https://www.skillsyouneed.com/ips/active-listening.html.

Slater, M., M. Usoh, and A. Steed. 1994. “Depth of presence in virtual environments.” In *Presence: Teleoperators Virtual Environ.* 3 (2): 130–144. https://doi.org/10.1162/pres.1994.3.2.130.

Slater, M., and S. Wilbur. 1997. “A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments.” *Presence: Teleoperators Virtual Environ.* 6 (6): 603–616. https://doi.org/10.1162/pres.1997.6.6.603.

Sun, Y., G. Albeaino, M. Gheisari, and R. Eiris. 2022. “Online site visits using virtual collaborative spaces: A plan-reading activity on a digital building site.” *Adv. Eng. Inf.* 53 (3): 101667. https://doi.org/10.1016/j.aei.2022.101667.

US Census of Bureau. 2021. “Computer and internet use in the United States, 2018.” Accessed August 23, 2022. https://www.census.gov/library/publications/2021/acs/acs-49.html.

Usoh, M., E. Catena, S. Arman, and M. Slater. 2000. “Using presence questionnaires in reality.” *Presence: Teleoperators Virtual Environ.* 9 (5): 497–503. https://doi.org/10.1162/105474600566989.

Weech, S., S. Kenny, and M. Barnett-Cowan. 2019. “Presence and cybersickness in virtual reality are negatively related: A review.” *Front. Psychol.* 10 (9): 158. https://doi.org/10.3389/fpsyg.2019.00158.

Wen, J., and M. Gheisari. 2020a. “A review of virtual field trip applications in construction education.” In *Proc., Construction Research Congress 2020: Safety, Workforce, and Education*. 782–790. Reston, VA: ASCE.

Wen, J., and M. Gheisari. 2020b. “Using virtual reality to facilitate communication in the AEC domain: A systematic review.” *Constr. Innovation* 20 (3): 509–542. https://doi.org/10.1108/CI-11-2019-0122.

Wen, J., and M. Gheisari. 2021. “VR-Electricians: Immersive storytelling for attracting students to the electrical construction industry.” *Adv. Eng. Inf.* 50 (Apr): 101411. https://doi.org/10.1016/j.aei.2021.101411.

Wilkins, B., and J. Barrett. 2000. “The virtual construction site: A web-based teaching/learning environment in construction technology.” *Autom. Constr.* 10 (1): 169–179. https://doi.org/10.1016/S0926-5805(00)00075-3.

Wilkins, K. G., B. L. Bernstein, and J. M. Bekki. 2015. “Measuring communication skills: The STEM interpersonal communication skills assessment battery.” *J. Eng. Educ.* 104 (4): 433–453.