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Applying Systematic Learning Progression in Online Construction Site Visits

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Virtual site visits are increasingly becoming a viable educational tool for educators to supplement or replace traditional visits when these are challenged by logistical issues, inaccessibility, or safety hazards. Recent research has explored the integration of theory-based learning strategies, such as collaborative problem-solving and multimedia learning, in online construction site visits to support construction students' collaborative skill development and learning effectiveness. However, there remains a lack of understanding of how to guide students systematically from conceptual knowledge to more complex, hands-on, or procedural knowledge, which often leads to a fragmented learning experience in current online site visit designs. This study aims to integrate active learning approaches (i.e., systematic learning progression) into online site visits to facilitate students' development of situated knowledge. In this project, a collaborative online site visit focused on building mechanical systems was created, where students worked in pairs to achieve four specific learning objectives, progressing from conceptual to procedural knowledge regarding building mechanical systems. The findings provide insights into the integration of systematic learning progression within virtual collaborative spaces for online site visits and demonstrate the effectiveness of such site visits in supporting students' situated knowledge.

Keywords: Online site visits; Construction education; Virtual collaborative spaces; Active learning

Introduction

Virtual site visits have become an increasingly valuable tool in construction education, particularly when traditional site visits face logistical, financial, safety, or accessibility limitations (Eiris, Sun, et al., 2022; Sun & Gheisari, 2021; Wen & Gheisari, 2020). Virtual site visits create a learning environment that allows learners to bypass the need for physical presence, effectively overcoming the spatial and temporal challenges often associated with traditional site visits. Leveraging these advancements, virtual site visits have been applied in the construction field to address learning obstacles within real-world contexts. They offer learning opportunities across various applications, including design review (Kandi et al., 2020), problem-solving (Eiris et al., 2021), collaboration (Eiris, Wen, et al., 2022), plan-reading (Sun et al., 2022), and safety training (Sun et al., 2024). Despite their advantages, virtual site visits often struggle with inconsistencies in content delivery and frequently lack well-structured instructional support. Traditional instructional frameworks generally begin with concept-based or declarative knowledge before progressing to more complex, procedural knowledge

(Anaya et al., 2022). However, current virtual site visits predominantly offer a one-dimensional learning experience, often focused on specific difficulty levels within construction-related knowledge. For example, Sun et al. (2022) used a virtual collaborative space to provide construction students with a spatiotemporal context for plan-reading practice. In this setup, students worked in pairs to interpret 2D drawings and explore corresponding 3D building models, but without a systematic learning progression or structured guidance moving from concepts to applications. Although this environment offered a safe and immersive space for plan-reading and collaborative practice, students' learning outcomes, when compared to those in a traditional video-conference learning environment, did not show significant improvement. Previous projects lack a systematic learning progression (Turk et al., 2019) that guides students from declarative to procedural knowledge, leading to incomplete retention and application of the acquired knowledge. Consequently, the transferability of knowledge during virtual site visits may not match that achieved in real-world settings or traditional in-person instruction. To address this gap, this study proposes a collaborative online site visit focused on a building mechanical system, integrating an active learning strategy through a systematic learning progression. This approach aims to facilitate students' development of situated knowledge and enhance their learning effectiveness in online site visits. The research goal of this study is to investigate the effects of systematic learning progression on students' knowledge construction and collaborative problem-solving behaviors during online site visits.

Literature Review

Virtual site visits serve as an alternative pedagogical tool, supplementing or substituting traditional site visits in construction education when logistical, accessibility, or safety challenges arise. Virtual site visits effectively simulate the spatiotemporal contexts of construction sites, enabling students to observe and understand construction projects, facilitate spatial skills, and apply conceptual knowledge to real-world scenarios. These virtual site visits have been utilized to enhance students' construction learning experiences, ranging from familiarizing them with built environment disciplines. (Shen et al., 2012) and facilitating a deeper understanding of the complexity of construction sites (Zhang et al., 2017) to augment their comprehension of building structures (Eiris, Wen, et al., 2022). Although substantial research has investigated virtual site visits, challenges remain in ensuring these virtual environments fully support student learning. Most evaluations of virtual site visits, specifically for educational applications, have focused on interactive experience elements like immersion, presence, engagement, and usability. (Sun et al., 2024; Zhang et al., 2017). However, there is a need to examine the pedagogical effectiveness of virtual site visits from a foundational educational perspective. In traditional construction education, knowledge construction requires students to explain, implement, and validate their solutions through complex, ill-structured problem-solving tasks. To facilitate this learning process, the concept of systematic learning progression has been used to create an instructional environment that guides learners from an initial lack of ability to proficient task execution. (Cook et al., 2013).

Systematic learning progression in science education was defined as "empirically grounded and testable hypotheses about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practice grow and become more sophisticated over time, with appropriate instruction" (Osborne et al., 2016). The progression from declarative knowledge to procedural knowledge is a fundamental aspect of educational frameworks, focusing on the transition from theoretical understanding (declarative knowledge) to practical application in real-world tasks (procedural knowledge). Systematic learning progression is commonly paired with learning outcomes, which are reflected in the changes to a learner's cognitive abilities. These cognitive outcomes encompass the acquisition and application of both declarative and procedural knowledge. (Kraiger et al., 1993). For example, Sitzmann et al. (2006) demonstrated that systematic learning progression in education can effectively bridge the gap between conceptual and applied knowledge by gradually introducing students to complex tasks, enhancing their self-efficacy and academic motivation. This learning strategy has become particularly valuable in construction education to ensure comprehensive student understanding. For example, Cook et al. (2013) evaluated the integration of Building Information Modeling (BIM) into higher education curricula by assessing students' foundational and procedural knowledge to identify instructional design methods that strengthen students' BIM proficiency. Similarly, Zwikael et al. (2015) utilized students' learning performance on declarative and procedural knowledge as metrics to evaluate the effectiveness of simulation-based training in project management education. While this instructional approach is well-established in traditional and physical construction education, its theoretical foundations and usability within virtual construction site visits have not been extensively explored. To ensure that construction students experience comprehensive knowledge construction in virtual site visits, this study proposes a collaborative online site visit integrating a systematic learning progression strategy. This strategy moves from declarative to procedural knowledge, specifically focused on building mechanical systems, to provide students with a structured pathway for effective learning and skill development in virtual environments.

Study Method

The goal of this study is to investigate the impact of systematic learning progression on students' knowledge construction and collaborative problem-solving behaviors during online site visits. This goal is addressed through the following objectives: (1) establishing a clear workflow for designing and implementing systematic learning progression in online site visits; (2) evaluating the effectiveness of this learning strategy in the online construction site visits; and (3) assessing the system's usability. Three steps were accomplished to achieve this goal. First, learning content related to building mechanical systems was developed using a systematic learning progression strategy, adapted for the online site visit environment. Next, this content was integrated into virtual collaborative spaces equipped with various collaborative communication affordances to support and scaffold students' collaborative problem-solving activities. Finally, students' feedback regarding system usability, learning outcomes, and collaborative problem-solving behaviors, was collected and analyzed.

Learning Content Generation

The learning content in this online site visit focused on building mechanical systems, a core subject frequently explored during site visits. (Eiris & Gheisari, 2017). Following a systematic learning progression strategy, four sequential learning objectives were developed, based on the curriculum of a standard introductory course in mechanical construction. (Koontz & Alter, 1996; Korman, 2015). These objectives include two declarative and two procedural learning goals, organized as follows: (1) describing the major components of an all-air HVAC system, (2) interpreting mechanical drawings and specifications, (3) understanding the applications of VAV in an all-air HVAC system, and (4) understanding air volume calculations. This online site visit consists of six scenes: an introductory scene, four learning sections (each dedicated to one learning objective), and an assessment section (Figure 1). In the introduction scene, students become familiar with the user interfaces and their tasks within the online site visits. The four learning objectives are each represented in dedicated learning scenes, integrating the relevant content within virtual collaborative spaces. The assessment section evaluates students' learning outcomes based on the knowledge acquired in the learning sections.

Online Site Visit Development

The virtual experience was designed using Mozilla Hubs, a virtual collaborative platform chosen for its device-agnostic features and minimal hardware and software requirements, allowing users to access the virtual site visit experience through a web browser. (Sun et al., 2022). To foster collaborative problem-solving behaviors in the online site visit, several collaborative communication affordances were integrated, including user embodiment, co-location in the virtual space, virtual pointer, and voice and text-based chat. 3D models were developed using Autodesk Revit and Blender. These models were then enhanced with multimedia elements, such as audio, video, and images, to enrich students' online learning experience and improve engagement through interaction with diverse media. These learning contents and media were integrated into Mozilla Spoke, a web-based platform for editing virtual scenes and published in Mozilla Hubs.

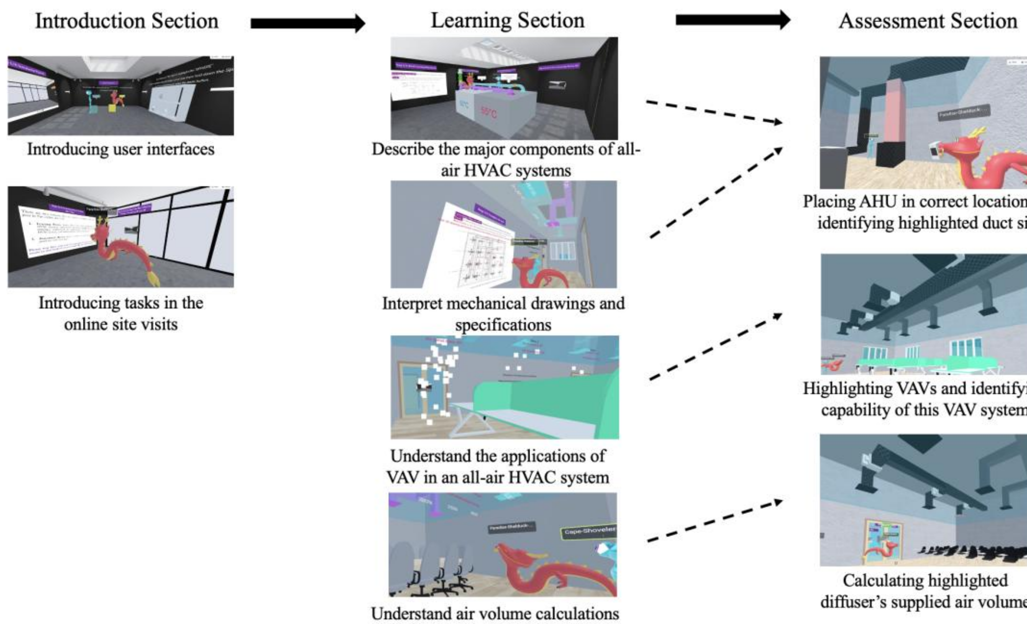

Figure 1. Introduction, learning, and assessment sections in online site visit

Experimental Assessment

A pilot study was performed to explore the impact of systematic learning progression on students' knowledge construction and collaborative problem-solving behaviors during online site visits. To maintain a consistent experimental environment, the study was conducted at a designated in-person location. Pairs of participants were randomly assigned to groups and completed all online site visit activities using lab computers. These computers were positioned in separate corners of the room to ensure a consistent internet environment and to prevent face-to-face communication. Data collection began with students completing a consent form and a demographic survey, which gathered information on their educational backgrounds and experience with building mechanical systems. Following this, students participated in online site visits on their assigned computers. During the activities, students completed a series of collaborative tasks using information provided in the virtual environment and supplementary handouts. Researchers were available within the virtual environment to provide pedagogical support, troubleshoot technical issues, and clarify instructions as needed. Throughout the site visits, experimenters observed and recorded students' behaviors for video documentation. This observation included tracking their interactions with virtual sharing features and communication tools, analyzing collaborative problem-solving behaviors, and documenting any pedagogical scaffolding provided. Upon completing the online site visits, participants filled out surveys to reflect on their experience. The experiment protocol for data collection was approved by the University of Florida Institutional Review Board (IRB# ET00019630).

This pilot study focused on understanding learning through three primary metrics: student behaviors, learning performance, and system usability. Student behaviors involved measuring the use of collaborative communication tools and instructor scaffoldings during online site visits. Observations from the video recording of student interaction were used to capture the frequency and purpose of student virtual field trip tools usage (i.e., voice and text-based chat, virtual pointer, and emoji). Additionally, the number of instructor scaffoldings and the reasons for providing them were documented from video observations to analyze instructional support provided during the activities. Students' learning performance was evaluated based on the accuracy of their responses in a virtual activity within the digital field trip, providing insight into their understanding and retention of the material covered during the site visits. Lastly, the usability of the system was measured using the System Usability Scale (SUS), a validated tool developed by Bangor (2009). The overall SUS score served as an indicator of the system's usability and feasibility.

Results and Discussion

Demographics

A total of 28 students (14 pairs) participated in the online site visit study. Table 1 shows their demographic information. Participants were recruited from the Rinker School of Construction Management at the University of Florida. Since the educational interventions were designed within the context of Mechanical Systems Courses in Construction, purposive sampling was employed to select participants (Etikan, 2016). While these students had been introduced to construction drawings and the fundamentals of construction management, they lacked familiarity with building mechanical systems. This means that, although they understood the general role of HVAC systems in construction projects, they were not knowledgeable about the primary components of HVAC systems or the interpretation of mechanical specifications in 3D structures and 2D drawings. These topics were covered during the online site visits, allowing us to assess students' learning experiences as they engaged in collaborative problem-solving within these virtual environments.

Table 1. Participant demographics

Parameters	**Category**	**Number (Percentage)**
Gender	Female	6 (21.43%)
	Male	22 (78.57%)
Educational Background	Construction Management	28 (100.00%)
	Other (e.g., Architectural and Interior Design	0 (0.00%)
Years of experience in the industry related to building mechanical system	None	22 (78.57%)
	Less than 1 year	4 (14.29%)
	One year to two years	0 (0.00%)
	More than two years	2 (7.14%)
Enrolled in the course "BCN 4510C – Mechanical Systems" or any other course related to mechanical systems	Yes	0 (0.00%)
	No	28 (100.00%)

Student Behaviors

During the online site visits, participants utilized various collaborative communication tools within the virtual collaborative spaces to support their collaborative problem-solving tasks. Figure 2 shows the four primary tools that were frequently used: text-based chat (share solutions and clarify misunderstandings), virtual pointers (document the problem-solving process and highlight items for peer reference), emoji (express emotions during problem-solving), and voice chat (allow continuous communication and real-time discussion). Since voice chat was active throughout the entire experiment, its usage was not recorded in instances, unlike the chat box, virtual pointer, and emojis, which had measurable, discrete instances of use. Table 2 summarizes student behaviors in using these collaborative communication tools. Among these, the virtual pointer was the most frequently used tool during the site visits. This interaction involved virtual rays emanating from avatars, which allowed students to engage directly with the environment by highlighting specific items within the 3D spatial setting. This functionality allowed students to seamlessly connect 2D drawings with their corresponding 3D in the virtual surrounding context, fostering a deeper spatial understanding of building system components. Additionally, text-based and voice-based communication enhanced peer collaboration and facilitated the efficient navigation of problem-solving tasks within the virtual environment. A student's response, *"I could see in 3D precisely when my partner highlighted the 2D drawing within the virtual environment, indicating their current location within the 3D building."* This underscores the effectiveness of the virtual context in bridging the gap between conceptual and spatial understanding, which is a critical skill in construction education. It also highlights the pivotal role of interactive tools in enhancing engagement and fostering comprehension within virtual environments.

Chat box (text-based chat): Sharing solutions and clarifying misunderstandings for peers

Virtual pen/pointer: Documenting the problem-solving process; demonstrating to peers which items were examined

Emoji: Expressing students' emotions during solving problems

Figure 2. Students' Behaviors Using Collaborative Communication Tools

Table 2. The number of instances a student interacts with Collaborative Communication Tools

Parameters	**Mean (SD)**
Text-based chat	1.14 (0.36)
Virtual pointer	4.79 (3.21)
Emoji	0.14 (0.36)

To ensure the success of collaborative problem-solving activities, experimenters or instructors provided scaffolding during online site visits. These scaffolds addressed both collaborative learning challenges and technical issues within the virtual collaborative spaces. For collaborative learning, the scaffolds included encouraging teamwork, providing hints to redirect students when they were engaged in unnecessary problem-solving processes, and helping them locate correct task descriptions if they were reviewing incorrect ones. When students were uncertain about their tasks, instructors clarified instructions and reminded them not to view answer sheets before completing tasks, highlighting that reviewing answers afterward could aid in learning, especially if they hadn't done so already. Additionally, if students became distracted by exploratory features in the virtual collaborative space (such as taking photos or drawing with the virtual pen), instructors prompted them to refocus on the remaining tasks. Technical scaffolding addressed issues such as assisting students with moving objects within the virtual environment, troubleshooting microphone issues, guiding students in using the virtual pen, helping avatars navigate, and redirecting students who became disoriented due to not following instructions in online site visits. Table 3 presents the results of instructional scaffolding use during online site visits. Observations revealed that instructor scaffolding was essential for the successful progression of online site visits. In traditional site visits or lectures, instructors guide students through content and provide support in problem-solving as students learn new knowledge. In these online site visits, with instructors acting as virtual teaching agents, students were expected to learn through collaborative problem-solving with their peers, utilizing hints to overcome obstacles. For example, one student indicated, *"It helped me to learn collaboration by sharing tasks and splitting them up while remaining in communication with my partner."* Instructor scaffolding allowed researchers to understand common challenges students faced, providing insights that will inform improved learning processes, content, and hint designs for future online site visits.

Table 3. Results of instructor scaffoldings

Parameters	**Mean (SD)**
Collaborative learning issues	1.36 (1.15)
Mozilla Hubs technical issues	0.91 (1.59)

Learning Performance

A knowledge test was used to assess students' understanding of building mechanical systems. On average, students correctly answered 77.04% of the assessment questions, indicating a relatively high level of foundational understanding of the building mechanical system. This success rate aligns with findings from other studies that have examined the use of VR systems in construction education to enhance learning outcomes (Sun et al., 2022). Sun et al. (2022) also evaluated students' learning performance in an online site visit developed using Mozilla Hubs. To differentiate students' learning performance in declarative and procedural knowledge, the assessment questions were categorized accordingly. Declarative knowledge questions focused on describing the major components of an all-air HVAC system and interpreting mechanical drawings and specifications. Procedural knowledge questions assessed understanding of the applications of VAV in an all-air HVAC system and air volume calculations. Students scored, on average, 72.22% in declarative knowledge, lower than their 85.71% accuracy rate in procedural knowledge. The lower scores in declarative knowledge suggest that students faced initial challenges with theoretical concepts, likely due to their limited prior exposure to building mechanical systems. Declarative tasks required students to understand and interpret technical details, which may have been affected by the cognitive demands of adapting to the virtual environment. In contrast, the higher scores in procedural knowledge reflect the benefits of systematic learning progression in guiding students through hands-on tasks. The step-by-step structure of the virtual site visits enabled students to apply their understanding more effectively, reinforcing their learning as they advanced through the activities. These results highlight the importance of balancing declarative and procedural learning in virtual environments. While declarative knowledge lays the foundation for understanding core concepts, procedural knowledge builds on this by emphasizing practical applications. A well-structured approach, like systematic learning progression, is crucial for helping students transition smoothly between these knowledge types, enhancing their overall competence in construction education. Additionally, prior research has shown that there is a positive relationship between knowledge retention, spatial abilities, and communication skills (Eiris et al., 2021; Eiris et al., 2022). Therefore, there is a need to improve spatial abilities and communication to increase the likelihood of student success during situated collaborative activities. Future research should consider integrating spatial skills training within the learning content to explore the benefits of systematic learning progression and online site visits in developing these skills.

Table 4. Correct responses to knowledge test

Parameters	**Mean (SD)**
Declarative knowledge	72.22% (18.18%)
Procedural knowledge	85.71% (17.61%)
Overall	77.04% (16.01%)

System Usability Scale (SUS)

In this study, the overall SUS score amounted to 75.00, signifying a level of system usability ranging from "Good" to "Excellent" (Bangor, 2009). A detailed analysis of individual statements provided further insights into the system's usability (Table 5). Overall, the online site visits were considered user-friendly, with participants expressing confidence in navigating both the learning and assessment sections. However, some technical issues were noted that require improvement. Users occasionally encountered challenges such as audio inconsistencies, image distortion, blurriness, and extended loading times. These issues, while not significantly impeding overall usability, highlight the need for more robust and reliable platform designs. Future iterations of virtual site visits should incorporate advancements in VR technology, such as platforms with faster loading times, enhanced graphical fidelity, and more stable audio-visual integration.

Table 5. Results of system usability scale (SUS)

Likert Scale: Strongly Disagree (1) – (5) Strongly Agree	**Mean (SD)**
#1: I think that I would like to use this system frequently	3.70 (1.13)
#2: I found the system unnecessarily complex*	2.83 (0.90)
#3: I thought the system was easy to use	3.53 (0.92)
#4: I think that I would need the support of a technical person to be able to use this system*	1.90 (1.16)
#5: I found that the various functions in the system were well-integrated	3.80 (0.91)
#6: I thought there was too much inconsistency in this system*	2.90 (0.87)
#7: I would imagine that most people would learn to use this system very quickly	3.43 (1.09)
#8: I found the system very awkward to use*	2.23 (1.15)
#9: I felt very confident using the system	3.43 (0.92)
#10: I needed to learn a lot of things before I could get going with this system*	2.23 (1.23)
Overall SUS (Bangor et al., 2009):	75.00

**Statements 2, 4, 6, 8, and 10 are worded negatively.*

Conclusion and Future Works

This research integrated an active learning approach, specifically systematic learning progression, into online site visits to enhance students' development of situated knowledge. To achieve this, a collaborative online site visit focused on building mechanical systems was created. Students worked in pairs to achieve four specific learning objectives, divided into two knowledge types (i.e., declarative and procedural knowledge) related to building mechanical systems. Observations were conducted on students' use of collaborative communication tools and instructor scaffolding to support their collaborative tasks in the virtual site visits and their performance on declarative and procedural knowledge assessments. The results showed that the virtual collaborative spaces in online site visits effectively supported students' collaborative tasks using various communication tools. The virtual pointer proved to be a valuable tool in spatial learning environments, enabling students to interact directly with the 3D setting by highlighting specific elements. Instructor scaffolding was also critical for the successful progression of online site visits. In this setting, instructors acted as virtual teaching agents, supporting students in collaborative problem-solving tasks by providing hints and clarifications to overcome obstacles. Looking forward, integrating AI technology to simulate real instructors could further support students' collaborative tasks in online site visits. The assessment results indicated a high level of foundational understanding of the building mechanical system. When the systematic learning progression was incorporated, students performed better on higher-level cognitive tasks within the collaborative setting. Future studies might compare systematic learning progression with non-systematic learning progression in online site visits to better understand its impact on students’ spatial skill and communication ability development for collaborative practices in virtual construction education.

This study has several limitations that highlight opportunities for future research. The pilot study’s limited sample size of 28 participants restricts the generalizability of its findings. Expanding future studies to include larger and more diverse participant groups could better validate the effectiveness of systematic learning progression across varied contexts and demographics. Additionally, the study’s focus on building mechanical systems narrows its applicability. Broader applications to other construction domains, such as structural systems, safety training, or project management, could find different insights into the role of systematic learning progression and virtual collaborative platform in construction education. In terms of usability, online site visits provided a user-friendly system that supported student interaction with 3D objects, communication tools, and learning content in a virtual environment, demonstrating the potential of online collaborative learning for future construction education. This project used Mozilla Hubs, a lightweight development engine, to create an online site visit. However, the platform was discontinued in May 2024. Despite this, its valuable features include diverse communication tools, straightforward development processes, and high accessibility. These benefits can be carried forward on other platforms like Spatial.io or Framevr.io. Moving forward, similar projects can be continued to explore the benefits of virtual collaborative spaces by integrating advanced, validated educational theories and technologies to support construction education.

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