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# Incorporating Pedagogical Theory into VR to Teach Civil Engineering

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**Abstract**

**Purpose –** The end of the Renaissance period in Europe saw civil engineering (CE) tuition develop from a master-apprentice relationship to the current classroom-based learning environment. This evolution allowed expertise to develop, but also created a situation where students could graduate from an engineering course without ever spending time on a construction site. The implementation of virtual field trips utilising virtual reality (VR) in CE education is a crucial development that can provide experiential learning to address this and can facilitate the consolidation of abstract theories into tangible competences. VR is uniquely able to solve a fundamental CE education problem: once a structure has been completed it is often impossible to see how it was built; hence, how can you explain the construction process to a student?

**Design/methodology/approach –** This research used the opportunity of a new campus library being built to record the construction stages. Researchers visited the site multiple times (starting from the construction of the building foundations), using both an Insta360 Pro stereoscopic camera and the GoPro Fusion to take photos and videos of the construction process, respectively. GoPro Fusion Studio was used to process the videos and the Insta360 Pro Stitcher was used to process photos. Unfortunately, many pedagogical VR projects do not result in worthwhile educational experiences for the user because attention is spent on the VR aspect of the project due to its novelty. By its nature, utilising VR as a didactic tool facilitates experiential learning, but this project will incorporate discovery learning and situated cognition to develop students' understanding of the construction process by being able to both (virtually) move around the construction site, and move backwards and forwards through the chronological constructional sequence. In addition to its pedagogical value, this learning resource will be made available to all students in future years.

**Findings –** The use of VR in education is becoming increasingly common, but the explicit pedagogy utilised by these environments is rarely obvious or stated.

This research draws upon current VR education discussions (Johnston et al., 2018) and explores the development of a VR environment with a pedagogical context. The goal is to create a VR learning environment for students that has pedagogical value and is not only of interest for its novelty value.
**Originality/value/implications –** The development of the resource draws upon the pedagogical frameworks of discovery learning (Bruner, 1961) and situated cognition (Lave & Wenger, 1991). A unique aspect of this research is the implementation of pedagogic theories into a VR environment to create an educational resource.

**Keywords:** education innovation; virtual reality; virtual field trip; civil engineering education; pedagogical frameworks.

## 1 Introduction

The *University of Nottingham Ningbo China* (UNNC), the first Sino-foreign higher education institution (SfHEI), was established in 2004 (Feng, 2013). It was established as part of China's on-going investment in improving both the quantity and quality of its higher education provision (Mok & Jiang, 2017), and is both an innovation and a centre of innovation (Towey, 2014). UNNC has encountered (and overcome) many challenges over its short history and has also seen many pedagogical innovations (not all of which have been successful; for example, Towey (2015)). The authors of this paper represent an interdisciplinary team at UNNC who, following identified best practices (Towey et al., 2017), came together to address a perceived shortcoming in current *civil engineering* (CE) education: the disconnect between the taught theoretical content and desired practical experience. Specifically, given our unique context of being the first SfHEI in mainland China to offer a British education, we chose to explore how mixed reality (Pan et al., 2006) may offer opportunities to enhance the CE curriculum at UNNC and elsewhere. After some initial exploration of how best to approach this problem (Towey et al., 2018b), a decision was made to take advantage of the on-campus construction of a new library building to develop a *virtual field trip* (VFT) of the construction process. Potentially aiming to develop a learning resource, preferably an *open educational resource* (OER) (Towey et al., 2018a, Towey & Zhao, 2017). Such an OER would make it possible for interested people (students and others) to explore aspects of the construction process that may not otherwise be possible, especially those parts that may become inaccessible after completion.

Further motivation behind this project was the potential for a VFT OER to enable classroom flipping (Lage et al., 2000; Bishop & Verleger, 2013) and the incorporation of experiential learning (Kolb, 1984) as part of a CE student's learning journey. Other advantages of a VFT include (as discussed previously in Towey et al., 2018b) the alleviation of the financial, logistical and safety issues associated with real field trips (Ramasundaram et al., 2005; Hurst, 1997; Jacobson et al., 2009). They also enable control over environmental aspects, such as scale, and backward/forward movement in time; thus enhancing the student experience in ways that are not possible in a conventional field trip. Additionally, they can help overcome mobility or distance challenges; thereby, promoting greater educational equity (UNESCO, 2018; United Nations, 2018; Green, 2017).

The aim of this paper is to demonstrate the design process used to create the pedagogic *virtual environment* (VE). In Section 2, the conceptualisation of the resource will be described alongside elaborations on how data was collected and used to build the VE. This will be followed by Section 3, which describes the educational activities that are suitable for facilitating student learning within the environment.

## 2 Designing the Environment

VR developers are faced with the problem of creating a VE that also functions as an educational resource. Specifically, how could the pedagogical theories of situated cognition, constructivism and discovery learning be implemented into a VE. In this study, the theory of direct instruction was not included because this is often the pedagogy of choice in student seminars and lectures. Furthermore, it is argued that it is also not necessary to explicitly include the experiential learning pedagogy into the design of the VE because it is an intrinsic part of the *user experience* (UX). Hence the question remains, how can an educational VE be created that incorporates the theories of situated cognition and discovery learning at the design stage.

### 2.1 Conceptual Framework

For technology to be used as a means for creating a learning experience, a simple virtual interactive teaching and learning mobile environment that is accessible from any location at any time is highly desirable. A photo-real environment that integrates the learning approaches of situated cognition (Brown et al., 1989), *data – information – knowledge – wisdom* (DIKW) (Ackoff, 1989) and *Active Collaborative Learning theory* (ACL) (Sibley & Osatfichuk, 2004) might successfully provide an autonomous learning experience in the field of CE and encourage legitimate engagement and participation. This conceptual framework is presented visually in Figure 2.1.

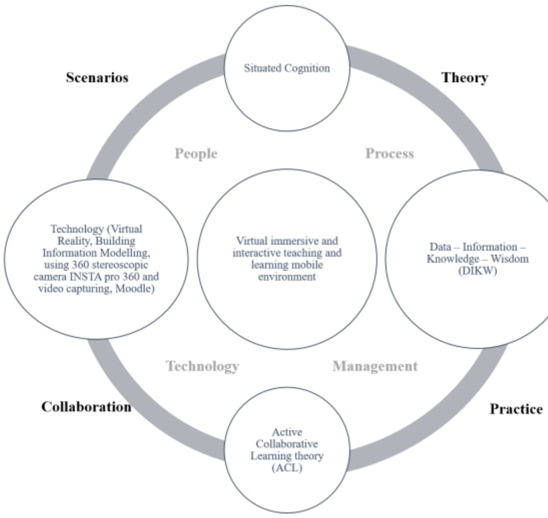


Figure 2.1. Conceptual Framework

Situated cognition explains that knowledge is associated with physical, social and cultural contexts (Brown et al., 1989) and was utilised by Šašinka et al. (2019) to build a *Collaborative Immersive Virtual Environment* for the purposes of teaching students hypsography. This intervention created a shared virtual room with users represented as avatars who were able to collaborate and communicate on a given task. Using an interpretative phenomenological analysis framework, it was found that participants appreciated having a collaborator (ibid), which supports the idea of implementing situated cognition in VR and echoes conclusions found from previous studies (for example, Johnson, 1999).

Furthermore, ACL theory is an educational implementation of the theory of situated cognition that uses technology to facilitate groups of students working together to solve a problem, complete a task, or create a product in a more dynamic and interactive environment. In other words it is “a special form of small group learning using a specific sequence of individual work, group work, and immediate feedback to create a motivational framework in which students increasingly hold each other accountable […] and contribute to discussion" (in Sibley & Osatfichuk, 2004).

Previous research has verified the efficacy of implementing ACL in student tasks. For example, Kapogiannis (2018) demonstrated that students achieved improved performance in their simulations of ‘Running a Construction Business’ when they implemented the principles of ACL into their practice. In this endeavour, the students used ACL whilst engaging in a virtual enterprise simulation (Construction Industry Simulations Ltd, 2000) and achieved marks with an average of 68%, which was a significant improvement on the previous years’ achievement when they achieved an average of 61% (ibid).

The DIKW framework (Ackoff 1989) states that the contents of the human mind can be classified into five categories: data, information, knowledge, understanding and wisdom; where, *data* is initially uninterpreted, *information* is gained by processing data, *knowledge* can be used to answer certain questions, *understanding* is the process by which humans can take knowledge and synthesize new knowledge from the previously held knowledge, and *wisdom* is the evaluation of understanding. In particular, this framework can be used to design and develop sophisticated applications or learning environments.

Therefore, the proposed integrated virtual and interactive mobile environment immerses CE students in a photo-real construction site where they can participate in team-based solution exercises consisting of construction project management, flood mitigation, structural analysis, construction site management, and health and safety. The on-site data collection process (using panoramic photos and videos) utilises the conceptual framework by following the DIKW process and implements ACL by bringing together students, practitioners, professionals, the construction process and technology. As a result, this integrated method utilises VR as a didactic tool to facilitate both experiential learning, discovery learning and situated cognition. It can be understood that when students visit a construction site, even in a virtual environment, they can learn new knowledge and create new understandings that are difficult to facilitate in a lecture theatre.

### 2.2 Technology and Environment Design

As recently as two years ago, taking a 360-degree stereoscopic photo with acceptable resolution was not a straightforward task. Practitioners typically used a tripod mounted digital SLR camera to take dozens of photos and then stitch them together using photo stitching software such as PTGui, for example. An alternative was to use several GoPro cameras and a purpose-built tripod such as an Omni to take photos from different angles, but from the same position and at the same time before using software to stitch.

Nowadays there are now many easy ways to do this with multiple technology companies developing high definition panoramic cameras making the technology widely accessible; including, using an aerial drone to take panoramic photos from the sky. In this project, an Insta360 Pro which has six lenses to take panoramic photos, and a GoPro Fusion, which has two lenses to take panoramic videos, were used for data capture on the construction site. To compliment these photos, a DJI Phantom 4 was used to take panoramic photos from the sky. These photos were taken at the completion of each phase of the construction process.

After the photos were taken, they required stitching to make a seamless scene for viewing either on a computer (by dragging the mouse) or in VR hardware. Both Insta360 and GoPro have their own stitching software (the Insta360 Stitcher and the GoPro Fusion Studio, respectively). This software stitches more quickly and precisely than previous software; however, it is still necessary to use PTGui to stitch photos taken by aerial drone.

After the panoramic photos and videos are stitched they are placed in the environment and users can navigate between them. Previous attempts to achieve this used a software called KRPano (for example) which had the advantage of creating the 360 environment easily; however, often the facilitator required their own server to store the materials and provide the website service. Nowadays, it is preferable to use an online platform hence for this project, the online platform 720yun was used for the 360-photo tour. After uploading the photos, the website provides editing functions, such as the ability to create hotspots and link different photos, additional information in different photo and video formats, and map of the area observed. One feature that is very useful but difficult to implement on a local server, allows the audience to comment on items within photos. This allows students to communicate with each other and to provide feedback on their learning experience.

Students can view the 360 tour on different devices, but for the purposes of working collaboratively, Google Cardboard was chosen. With Google Cardboard, students simply open the relevant link on their smartphone, enter the VR view and then put the phone into the cardboard. The screen will split so that a stereoscopic view is presented and crosshairs will be presented in the view. When students wear the cardboard, they can aim the crosshairs at hotspots and after two seconds this will change the view from one scene to another. An example is presented in Figure 3.2.

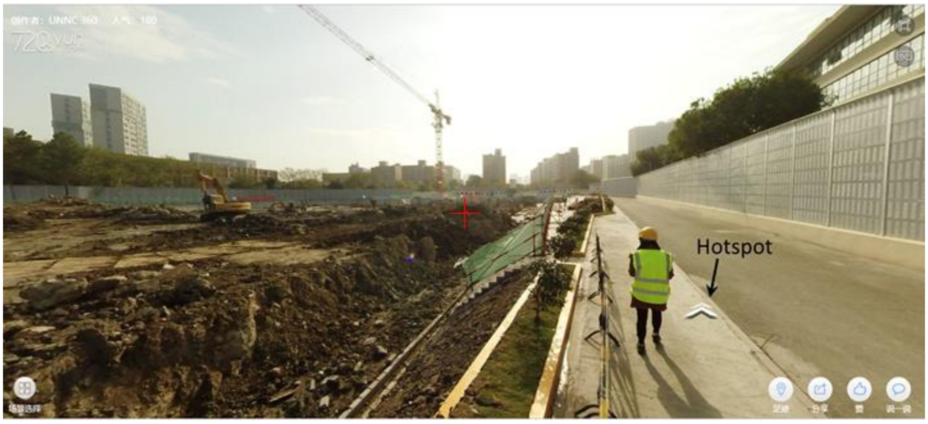


Figure 3.2 An Example of a Hotspot in the Virtual Environment

In figure 3.2, it can be seen that the direction of movement is given by the white and black arrows and the crosshairs are present in the centre of the picture. This arrangement was chosen because it allows multiple students to access the environment and work collaboratively without being restricted by hardware costs and without needing to use specialised handheld equipment.

When students are presented with the view in Figure 3.2, they are restricted by only moving backwards and forwards; however, if they wish to move to another part of the construction site, they need to visit the aerial view. At any point, if the students wish to have access to the aerial view of the construction site, they only need to look to the sky where a hotspot has been placed. On this aerial view, the locations of all photos have been placed for the purposes of allowing students to move around the site easily. An example of the aerial view with the hotspots is demonstrated in Figure 3.3.

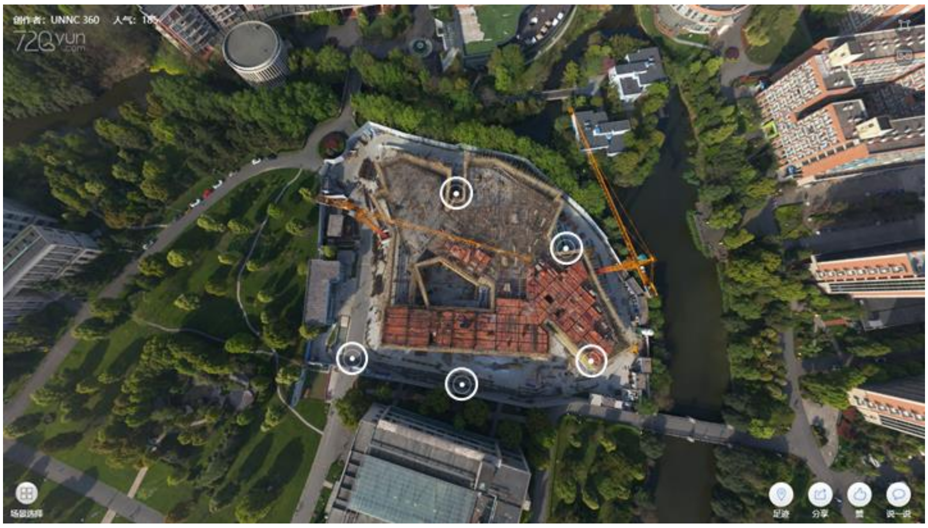
Figure 3.3. An Aerial View of the Construction Site.

Figure 3.3 shows an aerial view with five hotspot locations represented by the white circles. The user is able to travel to these locations by focusing the crosshairs on these spots for two seconds.

Finally, the students are able to stay in one spot and access photos at different times. This was achieved by looking at the sky and focusing the crosshairs on the time icons to either move forwards or backwards in time. An example is presented in Figure 3.4.

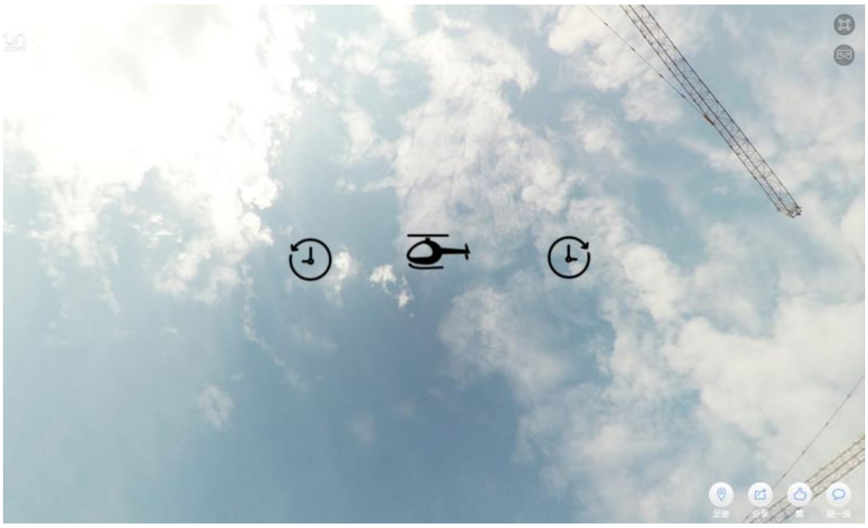
Figure 3.4 Icons for Moving Through Time or to the Aerial View

Figure 3.4 shows the three icons that are used to allow students to navigate. The first icon allows students to move backwards through time, the last icon allows students to move forward through time and the middle icon allows the students to go to the aerial view. The linking of multiple photos in this manner is a time-consuming task and students were utilised to help build the environment.

Finally, the VE is disseminated to the students using Moodle. Moodle is a learning management system designed to provide educators, administrators and learners with a single robust, secure and integrated system to create personalised learning environments. Links to the VE placed on Moodle provide easy access to all students from any location and at any time. This allows students to work together on projects that are designed to facilitate collaborative learning and examples will be provided in section 3. Consequently, this project incorporates both discovery learning and situated cognition into an experiential environment to develop students' understanding of the construction process.

### 2.3 Summary

The conceptual framework implementing a pedagogical framework has been explained. It can be seen that by developing a VE that is easily accessible to students, they are able to work together to complete projects; thereby, overcoming many of the drawbacks inherent when using VEs to teach students and creating a worthwhile educational experience.

## 3 Building the Environment

### 3.1 Introduction

This section describes some of the activities that were designed to incorporate pedagogical theory into VR for teaching CE at UNNC. All the activities require students to visit a construction site via VR to be able to complete the task.

### 3.2 Discovery Learning and Situated Cognition Activity

CE students at UNNC study a 30-credit coursework-based module called the "Civil and Structural Steel Design Project". The project requires students to collaborate, in groups of 5-6, to design a building on campus starting from the conceptual design and concluding by drafting technical engineering drawings for construction. In this module, students learn the principles of "framing" which requires them to understand how structural elements are connected and how they transfer or resist loads. The proposed VR project will provide each group with a 2-hour task to:

***Task 1*** (to be done in groups): Virtually visit a pre-defined area of the construction site and identify:

- Beams subjected both bending and shear;
- Beams subjected to bending, shear and torsion;
- Columns subjected to biaxial bending moments.

*Assessment:* Each group will be assessed by delivering a group presentation. They will be tasked with moving through the photo-real construction site and selecting different beams and columns for consideration; finally, deciding which are most suitable for presentation. Students will be asked to consider beams and columns from different parts of the construction area and during different construction phases. They will be motivated to work together because there will be a large number of structural members to assess (hence the volume of work is too great for one person alone) and when they have decided on potential candidates, they must discuss these in their groups and prepare their presentation.

***Task 2*** (to be done individually or in groups): Acting as structural engineer (or structural engineering team) working for a consultant, propose changes to a structure's frame to eliminate either torsion in a beam or a biaxial bending moment in a column. To complete this task, students must:

- Demonstrate their proposed change.
- Convince the consultant engineer that their proposed change is better for the building frame.
- Alter their proposed change (if necessary) following their discussion with the consultant engineer.

*Assessment:* If the task is to be done in groups then the assessment shall be aligned in a way to force all members of the group to discuss their work together using a similar approach to the one described in Task 1.

Task 1 requires the students to build on the knowledge they learn in classes and enter the VE in groups to discover and discuss how these specific structural elements visually look in an authentic building. They will have to use inquiry-based reasoning and make informed decisions to find these structural elements, which is a form of discovery learning (Dewey, 1938). Task 2 allows the students to engage in role playing which resembles a situation they may face in real life, and virtually interact and/or communicate with academics. Since students will access specific knowledge and practice what they learned within their community, situated cognition occurs (Duncan et al., 2012).

### 3.3 Discovery Learning Activity

Within the first two years of CE teaching at UNNC, students have to complete a 30-credit portfolio module. The module requires a collection of the students' work, accumulated over one year and each presented as a portfolio. The module requires students to decide on their own curriculum by participating in a set of workshops of their choosing and according to their personal development plan.

The *C1: Topic* workshop is one of the popular workshops. The workshop introduces typical themes in modern civil engineering, such as hydraulics, highways or structures, through lectures from industry experts and/or staff and supported by site visits and personal research. An online and asynchronous version of the workshop is to be introduced. The workshop plan is:

- Students attend an online introduction to the workshop; this can be done via Moodle;
- Students virtually visit a construction site and navigate through the different floors and construction stages.
- Students to choose a CE aspect (e.g. drainage, safety, construction methods, materials) and compile a report on how this aspect is implemented in the building. Each student will be required to receive workshop leader approval of their choice to ensure all students work in different aspects.

Students will be expected to discuss good and/or bad practices they discover during their virtual site visit and recommend action plans to avoid bad practices (if any exist).

Virtual site visits, similar to the one planned in this workshop, enable students to have access to the building during all construction stages at any time, allowing them to navigate backward and forward as they desire, an advantage traditional site visits lack.

### 3.4 Problems

There are potential perceived problems associated with implementations of the tasks described above. The problems may fall into two categories:

1. Difficulties in the technical development of the building in VR and troubleshooting during usage. In general, problems in this category can be solved with sufficient technical support.
2. How the students will evaluate their experience whilst completing the tasks in the VE and this will be investigated further after implementation. However, the choice of using Google Cardboard simplifies this issue. Furthermore, good, clear instructions and adequate equipment training can play a great role in enhancing students experience when embedding VR into civil engineering teaching.

## 4 Conclusion

This paper has described a method for implementing pedagogical theories into a VE. To date, no other VR applications have been designed by considering which pedagogies are appropriate to facilitate learning within a VE and then utilised existing frameworks to support them. This paper has explained that the frameworks of *Active Collaboration Learning* and *Data - Information - Knowledge – Wisdom* can be used to construct a learning environment that precipitates the use of situated cognition, experiential learning and discovery learning. These concepts have been applied to the teaching of civil engineering to undergraduates and will be included in the course delivered at UNNC from next year. In the future, the efficacy of this intervention will be assessed and improvements can implemented.

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