Instructional Design on Data Visualization Model of Using AR Sandbox Apps in Learning and Teaching Geography

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Abstract: Visualization of spatial data powerfully enhances our understanding of Geography in which map reading is one of the difficult skills for secondary teachers to teach. The AR sandbox provides a new tangible way to overcome this learning obstacle. Since the COVID-19 suspension has restricted the usage of authentic teaching methods since 2020, virtualizing the tangible sandbox into the mobile AR Sandbox app is necessary to continue learning and teaching Geography. Despite the technological breakthrough, a new pedagogy is required for adopting the technologies into effective teaching. Past research bodies found that the best use of the AR sandbox requires good learning instructions. The researchers develops the new data visualization model to convert spatial learning into the new AR/VR learning environment. This paper aims to outline an instructional design of the AR sandbox and conjecture a conceptual IPAD framework of the AR sandbox in some online fieldtrips with a seamless approach in teaching some geospatial concepts of Geography in Hong Kong's K-12 classrooms. Finally, some implications will be drawn for further research.

Keywords: augmented reality, AR sandbox, data visualization, mobile AR, tangible AR

1. Introduction

The technologies of mixed reality have become ubiquitous in classroom teaching. The AR sandbox is one of the best examples of applying AR technologies to the innovative Geography learning environment. The AR Sandbox has been utilized through augmented contour lines projection on the authentic sand. The projection in the tangible sandbox changes with "hands-on" movement. Students need to learn the 3D landscape by touching it to visualize some sophisticated concepts and their interrelationships in learning Geography. However, due to school suspension of face-to-face classes, the strict COVID-19 prevention instructions place great obstacles to the physical contact between students. Therefore, the action researcher (the first author) and the university academic (the second author) have converted the display and functions of the tangible AR sandbox into a mobile AR app. The mobile AR function provides the same topographic display in a virtual mobile AR view. Students can keep their "hands-on" experiences in the mobile app-based virtual environment. The AR sandbox app acts as a seamless learning tool which provides a high-mobility AR display in Geography.

2. Literature Review

2.1 Past Research Directions in Sandbox

The AR sandbox is a hands-on tool (Vaughan *et al*., 2017) that simulates Kolb's (1984) "experimental learning" in higher education in map reading (Healey & Jenkins, 2000). Majgaard & Weitze (2020) inspire our approach to experiential learning in a visual reality environment. The augmented image projections can be reproduced many times, allowing repeated learning cycles and changes in difficulties through the simulation image. The "experiential learning model" applies to students learning through the AR sandbox.

A comparison between pre-post testing experiments showed that students' test scores improved after using the AR sandbox (Carrera & Bermejo Asensio, 2017). Students learn more in the AR sandbox (Woods *et al.*, 2016). However, some researchers have argued that an AR sandbox only stimulates interest in learning and does not learn through the AR sandbox (Giorgis *et al.*, 2017). Jackson *et al.* (2019) proved that the effect of learning depends on pedagogy and time. Woods *et al.* (2016) also found that trainers need to adjust their classes to use multiple AR sandboxes during the semester to perform well. A multi-institutional study of inquiry-based lab activities using the AR Sandbox has recently indicated the benefits of using the AR sandbox without any learning instructions are not significant (McNeal *et al.*, 2019).

In Geography, data visualization (DV) is crucial. The map provides data visualization for our spatial thinking (Ellard, 2015). Understanding maps is an important method of learning Geography (Wellsted, 2006). In reality, map reading is not easy to teach (Jennings, 2011). Sánchez *et al.* (2016) suggested that the AR sandbox could be used for teaching and learning in secondary schools. Students can "experiment by changing the shape of the sand with their hands and experimenting with the changes in the topographic map." The use of 3D modellings does improve map-reading skills in K-12 Geography (Boardman, 1996). Digital maps may serve that purpose. However, most digital maps are web-based and viewed on a screen or tablet. The AR sandbox provides an authentic experience with sufficient modelling possibilities for teachers in normal lessons (Cárdenas-Delgado *et al.*, 2020).

This study in the paper focuses on pedagogical development and transformation of the 2015 version of AR Sandbox. It is designed to bridge the gap between 2D maps and 3D spatial concepts (Fisher *et al.*, 2019) and improve learning efficiency (c.f. Offermo, 2016).

2.2 Historical Development of AR in Hong Kong

The AR sandbox was introduced into Hong Kong by the first author in 2015 (reported on Singtao Daily, 2015.11.04). The AR sandbox has been well-promoted and widely used in secondary (and even primary) schools in Hong Kong (Lai, 2019). According to a local AR sandbox research, students' test scores had a 15% increase, and around 60% of students increased their length in answering after pre-test and post-test comparisons (Ku, 2017). Hence, the Education University of Hong Kong (EdUHK) conducted a pilot study and assisted the pilot school in Hong Kong in installing this teaching tool and a student at EdUHK carried out quantitative research in Hong Kong to study the usage of AR sandbox in schools (Hu, 2019). However, no local empirical research on pedagogical uses of AR sandbox has been conducted so far in Hong Kong. This motivates the first author of this paper to devise the most effective learning and teaching environment in Hong Kong (i.e. K-12 students in large classroom settings) through the AR sandbox. Owing to the school suspension under the pandemic attack, the first author has converted the AR sandbox's functions into an app-based environment to record learning and teaching progress through the functions of the AR sandbox.

3. Research Design

3.1 Emergence of the IPAD Framework in Learning and Teaching Geography

The conversion of the AR sandbox into an app-based environment under the emergence of the **IPAD** (Liu, 2016) framework is depicted in four successive phases in table 1.

Table 1. *Four Phases of the **IPAD** framework*

Phase 1	From reality to the tangible AR sandbox - **I**nformation gathering **(I)**
Phase 2	From tangible AR sandbox into the VR app environment - **P**rocess for visual enhancement (**P**)
Phase 3	VR app into mobile AR sandbox application - **A**pplying into seamless learning environment (**A**)
Phase 4	Bringing the enhancement learning environment into reality - **D**ata enhancement mobile learning (**D**)

This **IPAD** framework provides an innovative idea to integrate information for the researchers and users to develop and use the mobile AR sandbox app. during and beyond Geography lessons. Teachers and students may use the app to generate a virtual environment with the aid of AR images. The **IPAD** framework also helps consolidate the instructional design and draw pedagogical and learning reflections.

3.2 Instructional Design

The first author (the action researcher) uses a landslide to go through the **IPAD** framework in the case study. In the **IPAD** framework in figure 1, students are guided individually or in group settings to explore from a tangible sandbox in the real world to VR app environment. Then from that environment to the mobile AR sandbox app, the co-existence of AR/VR and real-world (R) helps students build / consolidate / revise some abstract or sophisticated geophysical concepts through data visualization.

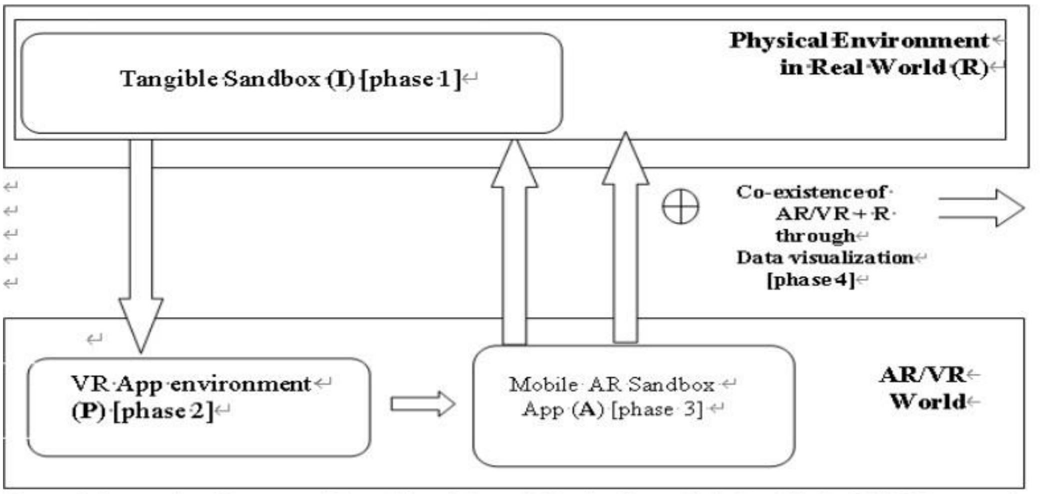

Figure 1. Interactions Between AR world and the real (physical) world depicted in the IPAD framework

3.3. Background of the AR Fieldtrip

This virtual field study is designed according to the three themes below:

1. **I**nformation: Exploring the Landscapes:
   Studying the area by the contour enhanced virtual 3D landscape.
2. **P**rocess and **A**pplication: Understanding the Risks
   Using AR technologies to add rainfall and reproduce the simulation of this event.
3. **D**ata enhancement: Managing the Hazards:
   Examining the usefulness of the check dam in the simulation.

The **IPAD** framework provides a way to organize the spatial data with AR/VR technologies. The literature review found that the AR sandbox lacks a pedagogical framework which is essential for being a better learning and teaching tool in Geography and Geoscience education. The **IPAD** framework requires teachers and students to gather the information (**I**), to process (**P**) the data and to apply (**A**) in real cases. Then, through the AR/VR technologies, the data enhancement (**D**) further enriches the visualization. It brings the map reading and virtual fieldtrip into high levels of conceptual understanding. It is not just a technological breakthrough but also a pedagogical renewal. Generally, AR visualization usually focuses on virtualizing the real world into the virtual world, which makes the virtual world real. But this study bridges the virtual world back to the real world. The virtual landscape displayed in the AR landscape creates realistic visualization for the users in figure 2.

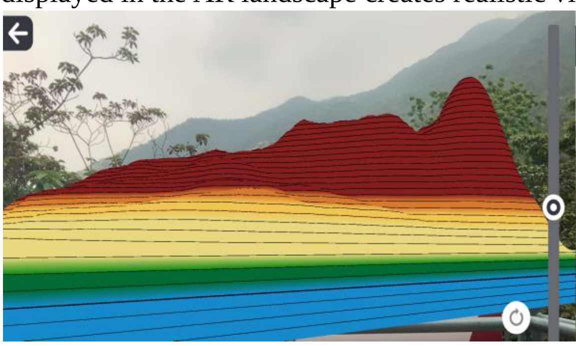

Figure 2. The AR Sandbox virtual terrain imposed in the AR background

Figure 3. The rainfall creates visualized enhancement in students' learning

Furthermore, rainfall mode provides the chance for students to experience a real-life situation, i.e. landslide after heavy rainfall in figure 3. Learning becomes more dynamic through the AR rainfall function. An AR landslide happens in the mobile AR environment.

With this technological and pedagogical breakthrough, Geography teachers may explore more of the AR fieldtrips in the future. Students may use the virtual 3D space and impose the information into real-life learning. Furthermore, any images with predicted changes may also use this technique to enhance the visualization of their virtual prediction.

4. Conclusions and Implications

The pedagogical usage of tangible AR sandbox, mobile AR Sandbox app and **IPAD** framework are still under-researched in local and international contexts. More data will be collected to reshape learning Geography and diversify the uses of the AR/VR technologies in learning and teaching Geography through the **IPAD** framework. If 3D maps or 3D mappings are bing assessed in upcoming open local and international examinations, there will be an assessment reform. Indeed (mobile) AR sandbox has an enormous potential to help improve student learning, reflected from the above preliminary action research results.

Further research agendas include:

- Possible conceptual changes in student learning Geography aided by the mobile AR Sandbox app
- Contextualized facilitators for and barriers against the **IPAD** framework
- Cognitive models accounting for how students' individualized connections between AR/VR and real-world (R) in the **IPAD** framework deepen their geospatial learning and scaffolding supports for peer co-construction of new concepts or correction of misconceptions

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