A Formative Evaluation on a Virtual Reality Game-Based Learning System for Teaching Introductory Archaeology

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Abstract: Virtual reality (VR) holds great potential for instructional and educational purposes as it is capable of immersing learners cognitively, physiologically, and emotionally by transcending physical limitations and boundaries, so learners can acquire experiences otherwise unattainable. A case in point is a VR learning environment that allows archaeology instructors to teach a variety of concepts and skills on archaeological fieldwork without bringing students to actual archaeological sites. A VR environment would also enable students to practice newly acquired skills in a safer and more affordable space than physically visiting the sites. VR alone, however, is insufficient to engage learners. Therefore, we identify game-based learning strategies to guide the development of the VR archaeology environment by incorporating game structure, game involvement, and game appeal into the design. The presentation reports an NSF-funded project that utilizes the HTC Vive VR system to host a game-based learning environment for teaching introductory archaeology classes in a US Midwestern university. The manuscript reports the design, development, and formative evaluation of the VR archaeology game grounded in learners' motivational and cognitive processes. In particular, the formative evaluation findings, based on 40 participants' responses, reveal various design opportunities and challenges for designing game-based learning experience in virtual reality environments.
Keywords: virtual reality,game-based learning,design,formative evaluation,archaeology,university,motivational support,cognitive support

Introduction

Archaeology has an inherent physical component and deals largely with three-dimensional objects, making it challenging to present in a traditional classroom. Having excavation experience is critical, and currently, archaeological education is hampered by the ability to provide it. For financial and logistical reasons, field experience is not an option for most students. At the same time, today's students are largely visual or visual kinesthetic learners, preferring to be engaged in course content through exploration and interaction (Jukes et al., 2010). These challenges are well met by the unique capabilities of virtual reality (VR), computer technology that creates a simulated three-dimensional world, thereby transforming data analysis into a sensory and cognitive experience. We are currently creating an immersive VR archaeological site that: 1) teach the physical methods of archaeological excavation by providing the setting and tools for a student to actively engage in field work; and 2) teach spatial and temporal concepts through a scientific approach to problem solving by couching them within a role-playing game.

Virtual reality technology currently has its home and largest application in the gaming industry. Generations of learners have grown up immersed in technology, and digital gaming has become ubiquitous (Jukes et al., 2010). As such, the presentation of educational content using a VR environment lends itself to a game-based approach. Many have agreed that game-based learning, with its multifaceted features and interoperability between different genres, is capable of engaging learners cognitively, emotionally, and socially (Raybourn, 2006).

Unique Affordances of Virtual Reality for Teaching Archaeology

Archaeological field work largely involves the manipulation of 3D objects. Theoretical and methodological issues become more real, comprehensible and intriguing if there is an opportunity to handle evidence and personally wrestle with fundamental problems of identification and quantification. VR is *not* a movie that you watch – it creates hands-on, participatory experiences in "realistic" environments. The physical action that is proposed with this project is designed to engage students in activity that is the same or very similar to the activity they would engage in in the real world as they learn foundational principles of a discipline. This whole-body immersion is also an effort to increase a student's physical engagement with digital content to reacquaint themselves with their body's sense of proprioception and physical cues that are absent in traditional digital displays like computer or phone screens. VR offers unique capabilities for learning and practicing archaeology, including:

- Physical interaction and manipulation of artifacts through intuitive interactions
- Opportunities outside a student's normal experiences
- Exploration and discovery that are part of archaeological field work but an impossibility in the real world; a student can intuit where and how to look for hidden objects in virtual space based on accumulated data and an ability to recognize patterns through repetitive experience
- Realistic recording and measuring of data (documenting location and description of artifacts *in situ)*
- Reconstruction and visualization of a bigger picture

Theoretical Foundation

Opportunities Afforded by Game-Based Learning

A game is a context in which individual and teamed players compete in attaining game objectives. Suits (1978) summarized the playing process as the "voluntary effort to overcome obstacles". Instructional benefits of digital game-based learning may include:

- Creating meaningful and hands-on problem-solving experiences for learners. Learners learn from their mistakes, and the mistakes of their peers, to improve skills and discover winning strategies.
- Enriching learning experiences by fostering interactions among learners and game systems.
- Affording a wide range of learning complexity, which benefit allows learners to develop versatile

problem-solving skills for science learning.

Design Model: Aligning Game Features to Motivational Support and Cognitive Engagement

The design of game-based learning must be guided by instructional design models and theories to effectively translate the underlying learning theories into feasible instructional features in the digital game-based learning systems. In this study we aim to align game features with intended motivational and cognitive learning outcomes. This study adopts the findings of the Motivational-Cognitive Learning Support model (Huang, Johnson, & Han, 2013) as the guiding design model. The model also provides tangible design factors for measuring perceived motivational and cognitive support in game-based learning environments.

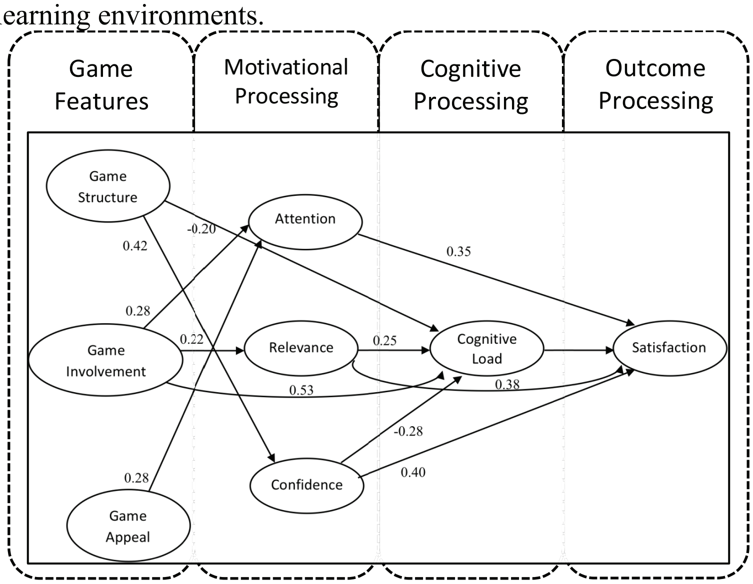

Figure 1. Empirical connections between game features, motivational support, and cognitive learning support (Huang et al., 2013)

Game-Based Learning Features

Game Structure

Enforcing rules **–** Rules embody problem-solving processes in various forms for learners to follow. Through the process of playing, learners can gain first-hand experience practicing a methodology to resolve given problems. Additionally, the game rules ensure fair play (Hays, 2005).

Goal-oriented tasks **–**The role of tasks in games is twofold. First, tasks are building blocks or performance benchmarks for players to achieve the winning goal. Second, game tasks help players assess their performance formatively. Incomplete tasks would require players to visit them until their performance meets the competency requirement (Csikszentmihalyi, 1990; Gredler, 1996).

Supporting learner autonomy – Players have a great extent of control over what paths to take to complete game tasks. This feature helps develop players' self-identities while sustaining their intrinsic motivation. Furthermore, the autonomy helps players develop a sense of ownership of decisions they make during the game play (Belanich et al., 2004).

Game Involvement

Presenting challenge and competition **–** The level of challenge in game tasks must only minimally exceed learners' potential competency capacity to overcome the obstacles, otherwise the learner may experience frustration in the early stages of play (Csikszentmihalyi, 1990; Garris et al., 2002; Rieber, 2001). In addition, competition differentiates game playing from other human activities. Players may compete with themselves, the game system, individual players, or other teams (Amory, 2007; Csikszentmihalyi, 1990).

Situating players in a fantasy world **–** Games enable fantastic explorations and experiences that are otherwise impossible to acquire (Kirriemuir & McFarlane, 2006). Players may be placed in a different spatial or temporal context to experience a different form of life (Amory, 2007; Csikszentmihalyi, 1990).

Immersing learners – This is the collective effect of many game features, which enables immerses players cognitively, affectively, physically, and socially. Players in turn consider themselves as part of the game. Competition, fantasy, fun, and mystery are often implemented into games to enhance the immersive effect (Csikszentmihalyi, 1990).

Allowing role-playing –Role-playing complements the challenge, fantasy, storyline, and engaging features of games. Players "pretend" to be someone or something else in all aspects of their interactions with the game system. This feature also enhances players' intrinsic motivation to perform continuously in a challenging game-based environment (Gredler, 1996).

Game Appeal

Utilizing multimedia representations – Today's digital games take full advantage of multimedia representations to embody the aforementioned characteristics. Not only do multimedia representations help reduce cognitive demand on players' limited capacities, but they also develop players' visual and spatial analysis skills (Ang et al., 2007).

Table 1. Game feature factor items from Huang et al. (2013) (Cronbach's alpha = .89)

Factors	Items
Game Structure	The game's rules are easy to follow.
	The game's goals are clearly presented.
	The game tasks are clearly presented.
	The game provides all information necessary for me before the playing process.
	The game provides all information necessary for me during the playing process.
	The game provides enough support to help me accomplish the game tasks.
Game Involvement	The game engages me deeply in the playing process.
	The game situates me in a fantasy world.
	The game allows me to role-play.
	The game keeps me interested throughout the playing process.
	The game is fun to play.
Game Appeal	The game's graphics are attractive.
	The game's animations are attractive.
	The game's audio elements (e.g., background music, narrations) are attractive.

The Innovation and Instructional Integration

This study test-designs a virtual reality scenario in which students are immersed in the methods and tools typically used by archaeologists to understand spatial and temporal concepts using the scientific method. As they proceed through a "dig," students will put these concepts into practice by critically thinking, generating ideas, and evaluating hypotheses within the context of a VR video game.

The subject matter delivered by this prototype is the equivalent of approximately four to six weeks of the curriculum in an introductory archaeology class (based on the syllabus of the Introduction to Archaeology course at a Midwestern US Research One land-grant university). The activity is designed for a single user with interaction and direction provided by the professor, as needed. The single-user game would later be combined into a larger, group-focused effort.

The virtual environment has been created based on the concept of a stratigraphic excavation, that is, a site formed by successive layers of soil deposited over a long period of time. The virtual excavation will be designed based on an actual research site in northern Laos, Tam Pa Ling. This is a cave site that is both visually engaging to capture students' interest and stratigraphically complex to promote advanced level excavation scenarios. It has the added benefit of being a novel and exotic location, lending itself to the "fantasy world" that is a feature of many digital and virtual games. A student is to be totally immersed in this environment with the ability to interact with its relevant features.

The project is developing a room scale virtual excavation experience based upon the HTC Vive VR platform, which is a high-quality, mass-produced, low-cost, consumer VR system that became available in 2016. It includes a PC with a VR-capable graphics card, the latest HTC Vive VR headset, two trackable hand controllers and two base stations for emitting a tracking signal. The headset is connected via a very long cable to the PC. Two base stations are installed at opposite sides of a room and project infrared laser stripes across the room, which are detected by photodiodes on the headset. Users hold controllers that can be tracked so that interaction with objects in the virtual world can be simulated. These affordances of the HTC Vive system allow us to most closely match the size and interactions of an actual excavation experience.

The virtual environment in which a student operates the VR system, a square region of 16 cubic meters, closely mimics the size and shape of a real excavation and should look as realistic as possible. The ground of the virtual world has been realistically rendered by texture-mapping techniques that use data from these photographs. The ceiling and four walls are rendered using panoramic video. The side and top viewing directions are mapped onto the four walls and ceiling in the virtual world. This enables students to feel like they are participating along with a larger team and obtain an immersive experience that is close to reality. See the screenshots below from the VR cave.

Formative Evaluation

A formative evaluation of the design and development activities was conducted to provide feedback and recommendations to the design and research team regarding the trajectory of the project based on the aforementioned design framework and intended learning outcomes. In addition, the formative evaluation could reveal the degree of implementation of the proposed design, research and development activities. Specifically, aligning with the discussed design framework and game-based learning features, this present study reports the formative evaluation findings on the evaluation question: *In what area and to what extent does the VR game-based learning environment support participants' motivational and cognitive processing?*

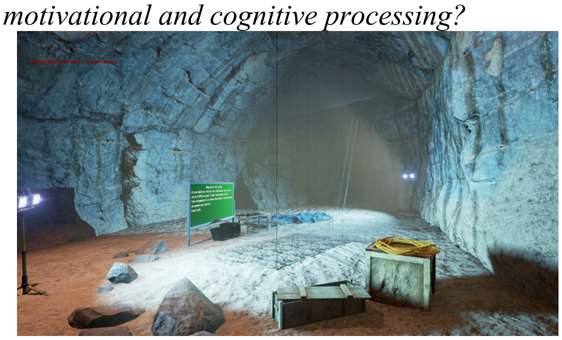

Figure 2. Screenshots of the VR cave.

Formative Evaluation Method and Process

The formative evaluation, following the small group evaluation method (Smith & Ragan, 2005), was conducted on a Midwestern US Research One university during a regular 16-week semester. The evaluation was able to recruit 40 undergraduate and graduate student participants through an on-campus anthropology course and recruiting emails during the period of 3 weeks.

See Table 2 for the participant demographics below.Each participant, upon providing written consent to participate in the evaluation, followed the process below to complete their participation:

1. Review a 7-min long instructional video on how to interact with the VR game-based learning module.
2. Complete the task in the VR environment, which entails retrieving digging apparatus, excavating the digging area with tools to locate artifacts, retrieving the measuring tape, measuring the artifacts, and return the digging tools and measuring tape to a designated area.
3. Complete on online survey on perceived motivational support, cognitive effort investment, and game features based on the VR experience. The survey consists of 64 items.
4. Complete a face-to-face interview on the overall VR experience and suggestions for improvement On average, each participation session took 45 min to complete.

Table 2. Demographics of the participants (N=40)

	# of Participants			#
Sex		Is this your first VR experience?		
Male	12		Yes	27
Female	28		No	13
Academic year				
Freshman	7	Is this your first VR experience for educational purposes?		
Sophomore	3		Yes	36
Junior	11		No	4
Senior	8			
Graduate	11			

Formative Evaluation Findings

The evaluation team was pleased to find that it did not take long to recruit enough participants on campus. The applied sampling frames and strategies seem to be effective in recruiting a diverse group of participants. The time needed to complete one participation session also provides benchmarks to design for large-scale evaluation activities. One limitation of the present evaluation design is its inability to accommodate multiple participation sessions simultaneously. In terms of the online survey, all instruments reported good scale reliability (Cronbach Alpha > .75) based on the 9-point Likert scale.

Preliminary Evaluation Finding

In terms of perceived motivational support, the Relevance component of the ARCS model was reported to be lower than the other three components (see Table 2). In addition, the germane cognitive load was reported to be the highest among all three types of cognitive load. See Table 3.

Table 3. Means of instrument constructs on a 9-point Likert scale

	Mean
Motivational support: Attention	7.42/9
Motivational support: Relevance	6.54/9
Motivational support: Confidence	7.86/9
Motivational support: Satisfaction	7.67/9
Cognitive effort investment: Intrinsic cognitive load	3.49/9
Cognitive effort investment: Extraneous cognitive load	1.47/9
Cognitive effort investment: Germane cognitive load	5.93/9
Game feature scale: Game structure	8.53/9
Game feature scale: Game involvement	7.87/9
Game feature scale: Game appeal	6.72/9

With regard to findings from the interviews, the interview questions were able to receive rich responses from the participants. Overall, participants found the VR experience appealing and enjoyable. The participants also recognized VR's educational values and limitation in teaching archaeology. Some selected quotes from participants' responses are listed below:

> *"I find Archaeology and anthropology in general very interesting and I really enjoyed having such an interactive experience with this. It's easy to read about it that this was a really good opportunity to get a feel for what I would like to see what it would be like to be in the field which is not something I've had experience."*
>
> *"The graphics are really good right off the bat when I put on the headset on. It was like wow, this is awesome and so that was really enjoyable. The actual excavation too was kind of nice because you knew you were looking for something so it's nice that there is a task involved instead of just like you know lecture information.*

When asked what would be one issue that needs improvement for the educational VR experience, participants centered on three aspects. First is the lack of sound in the VR cave. Second is the absence of background story or narrative to contextualize the VR experience. Third, the immersivity of VR cannot only rely on multimedia representations and interactive features. The complexity and involvement of in-game tasks are also critical for the VR cave to consider.

> *"I think some audio element I think would be the most important part. But other than that I was pleased."*
>
> *"I think just gave the cave a story, you know like this particular culture was in this cave, you are digging up this particular artifact for this reason. I think that would be helpful."*

Discussion and Recommendations

Users of VR game-based learning environments are applying three standards when deciding on engaging with the VR game-based learning or not. First, it is important to have interactive and user-friendly VR interface that simulates realistic activities. Second, it is important to connect the VR game-based learning experience with users' prior gaming experience derived from non-VR interfaces. Third, it is important to allow users to experience elaborated and scaffolded in-game tasks that are explicitly relevant to the intended learning outcomes. To a large extent, the VR learning environment, owing to its intuitive interface that allows users to interact with the system almost immediately, has shifted users' attention to the content delivered by the VR system, which could yield optimal learning outcomes.

In general, the formative evaluative activities are feasible to conduct. The evaluation team was able to recruit sufficient participants within a relatively short amount of time. Participants have provided comprehensive and constructive feedback to the intended VR game-based learning environment. The data collection instruments are reliable and conducive for gathering participants' responses. One potential limitation, nevertheless, would be scaling up the evaluative activities to more than 200 participants in an instructional setting for summative evaluation purposes. It is also desirable to gather participation data beyond participants' perceptions. Participants' physical movements during the VR game-based learning processes, for example, could provide insights on optimizing physical instructional spaces for multiple VR stations. We anticipate to resolve these issues by revisiting potential classroom and laboratory spaces and procuring additional data collection devices for just-in-time recordings.

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