

Relationships between Cognitive Loads and Motivational Support in a Virtual Reality Game-Based Learning System for Teaching Introductory Archaeology

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Abstract: While virtual reality (VR) might be effective in engaging learners with authentic and immersive learning experiences, current literature is lacking in understanding the relationship between learners' perceived cognitive loads and motivational support. In addition, it is unclear as to how the incorporation of game-based learning strategies might impact the overall efficacy of VR for instructional purposes. The presentation reports a NSF-funded project that utilizes the HTC Vive VR system to host a game-based VR learning environment for teaching introductory archaeology classes in a US Midwestern university. The presentation will also report the results of multiple regression analyses to delineate relationships between cognitive loads and motivational components based on survey responses of 106 participants. The presentation will conclude by discussing game-based VR design opportunities and challenges in terms of the role of motivational design, design efficiencies and their unintended consequences.

Keywords: virtual reality, game-based learning, design, cognitive loads, motivational design support

Problem & Proposed Solution

Like many natural sciences, a critical component of archaeology is field work. Excavation experience is critical, and in many cases, college and university anthropology departments require field experience as part of their undergraduate curriculum. 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). Similarly, research has repeatedly shown that these experiences significantly increase students' interest, learning, and problem-solving abilities (Boyle et al. 2007; da Silva, 2014; Fleischner et al., 2017).

The challenges of teaching archaeology in the classroom are well met by the unique capabilities of virtual reality (VR), a computer-generated simulation of a three-dimensional world that allows a user to interact with their environment in a natural way, thereby transforming data analysis into a sensory and cognitive experience. We present the design and delivery of an immersive, interactive virtual archaeology course for university undergraduate students that teaches archaeological theory and the physical methods of archaeological field excavation using game-based design. At the same time, we will assess the efficacy of this technology and its integration into a larger archaeology curriculum. In particular, we are focused on learners' perceived cognitive loads and motivational support to evaluate the effectiveness of game-based VR learning within this specific test case.

Theoretical Foundation

The incorporation of game-based learning strategies in VR 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. Such design alignment is crucial to support the full efficacies of instructional method (i.e., game-based learning) and instructional multimedia (i.e., VR) when combined together for immersive learning experience. This study adopts the Motivational-Cognitive Learning Support model (Huang, Johnson, & Han, 2013) as the guiding design model. The model also provides empirical foundations for this study to articulate the relationships between cognitive loads and motivational support. Relevant descriptions on game-based learning features are available at Shackelford et al. (2018).

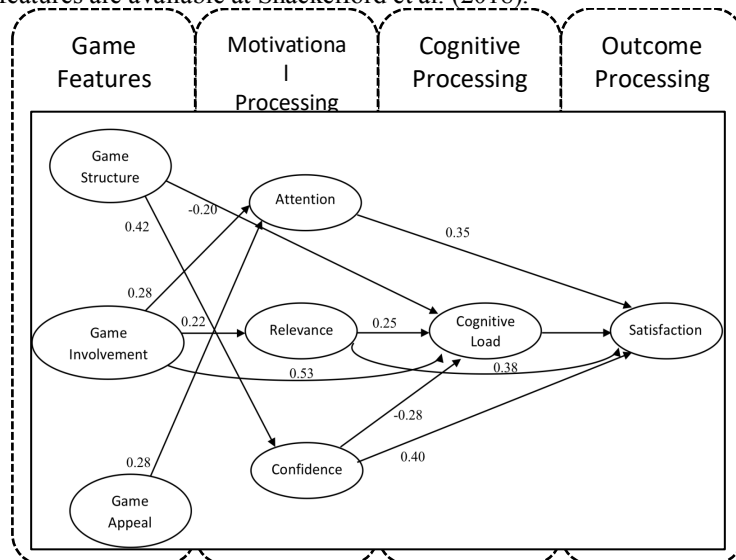


Figure 1. Empirical connections between game features, motivational support, and cognitive learning support (Huang et al., 2013)

Cognitive Load

Cognitive load is a multidimensional construct that includes task-based *mental load* induced by task characteristics, learners' performance, and *mental effort* invested by students in their working memory to process information (Paas, et al., 2003; Paas & van Merriënboer, 1994; Sweller, et al., 1998). Tasks with high complexity usually demand a high cognitive capacity, termed as *mental load*. *Learners' performance* refers to their achievement in terms of performance score and time spent on learning. There are three types of cognitive load that, when combined, compose total cognitive load: intrinsic, extraneous, and germane. For learning to occur, the total cognitive load can never exceed a student's working memory capacity. Intrinsic cognitive load is associated with the element interactivity—the degree to which information can be understood alone without other elements'

involvement – inherent to the instructional material itself. Information with high element interactivity is difficult to understand thus induces a high intrinsic cognitive load, since the instruction requires more working memory for information processing (Pass et al., 2003). The extraneous cognitive load and germane cognitive load, in contrast, *can* be manipulated by instructional design (Brüken, Plass, & Leutner, 2003). The objective is to *reduce* the extraneous load while *increasing* the germane cognitive load (van Gerven, Paas, van Merriënboer, & Schmidt, 2006).

Cognitive Load Theory also provides a framework to allow researchers to gauge students' mental effort investment (Kalyuga, 2009). The subjective category of the mental effort measurement, based on the assumption that people are capable of reporting their mental effort level with corresponding numerical values on a given rating scale (Gopher & Braune, 1984; Wierwille & Eggemeier, 1993), was often used as the main indicator of overall cognitive load in earlier studies because of its higher reliability, validity, and sensitivity to students' small cognitive load changes than two other categories of measurement (physiological and task/performance-based) (Paas, van Merriënboer, & Adam, 1994). Paas and van Merriënboer (1994) proposed a 9-point symmetrical category scale to ask students to report their invested mental effort where "1" corresponds to a "very, very low mental effort" and "9" indicates a "very, very high mental effort." Later a similar 7-grade symmetrical scale was proposed and tested by other researchers (Marcus, Cooper, & Sweller, 1996; Kalyuga, Chandler, & Sweller, 1998). This study adopted a 10-item scale to measure the perceived cognitive load (Leppink et al., 2013).

Motivational Support

The ARCS model (Keller, 1983, 1987a, b) suggests that learning motivation is dependent of four perceptual components: attention, relevance, confidence and satisfaction (Keller, 2008). What the model theoretically measures is the amount of *effort* invested by learners to achieve the learning goal (Small, 2000; Song & Keller, 2001).

Attention indicates learners' aroused curiosity upon interacting with the instruction (Keller, 1983). **Relevance** gauges the perceived usefulness and values of the learning experiences in relation to learners' prior experiences.

Confidence stresses the importance of building learners' positive expectation towards their performance on the learning task. **Satisfaction** is the measure of the reflection and evaluation on the ratio between invested efforts and perceived outcome (Keller, 1987b). Prior studies have utilized the 36-item Instructional Material Motivational Survey (IMMS) (Keller, 1993) derived from the ARCS model to measure motivational support of computer-based and interactive instructional programs with practical results. For instance, Huang and colleagues (2006) measured the motivational support of a computer-based tutorial for programming among 875 undergraduate students. The results were able to inform the implementation strategies of the tutorial in order to provide stronger motivational support to students. In a recent game-based learning study, Huang and colleagues (2010; 2013) also applied IMMS to evaluate the motivational support of an online educational game. Their findings suggested significant relationship among the ARCS components that can inform the motivational design of game-based learning.

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 an archaeological field methods class and 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 room-scale virtual environment was created based on the concept of an historical archaeological excavation. The virtual excavation takes place within a limestone cave system that is both visually engaging to capture students' interest and stratigraphically complex to promote advanced level excavation scenarios. A student is to be totally immersed in this environment with the ability to interact with its relevant features.

The project was developed using 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.

Relationships between Perceived Cognitive Loads and Motivational Support

The present study aims to delineate the relationships between learners' perceived cognitive loads and motivational support upon interacting with the game-based VR cave. The research team recruited 106 participants through an on-campus anthropology course and recruiting emails during the period of 20 weeks. See Table 1 for participants' demographic information. Each participant, upon providing written consent to participate in the evaluation, followed the process below to complete their participation:



Figure 2. Screenshots of the VR cave.

1. Review a brief 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 an online survey on perceived motivational support and cognitive effort investment, and game features based on the VR experience. The survey consists of 46 items.

| | | # of Participants | | | # |
|---------------|-----------|-------------------|--|--|----|
| Sex | Male | 36 | Is this your first VR experience? | | |
| | Female | 70 | Yes | | 71 |
| | | | No | | 35 |
| Academic year | Freshman | 22 | Is this your first VR experience for educational purposes? | | |
| | Sophomore | 12 | Yes | | 98 |
| | Junior | 23 | No | | 8 |
| | Senior | 18 | | | |
| | Graduate | 29 | | | |
| | Other | 2 | | | |

Table 1. Demographics of the participants (N=106)

Findings

All online survey instruments reported good scale reliability (Cronbach Alpha > .75) based on the 9-point Likert scale. Regarding the perceived cognitive loads, the germane cognitive load (6.16) is the highest; the extraneous load is the lowest (2.27). In terms of perceived motivational support, the Satisfaction component of the ARCS model was reported to be lower than the other three components. See Table 2.

| Sub-scales | Mean |
|--|--------|
| Motivational support: Attention | 7.40/9 |
| Motivational support: Relevance | 6.50/9 |
| Motivational support: Confidence | 7.12/9 |
| Motivational support: Satisfaction | 7.47/9 |
| Cognitive effort investment: Intrinsic cognitive load | 3.95/9 |
| Cognitive effort investment: Extraneous cognitive load | 2.27/9 |
| Cognitive effort investment: Germane cognitive load | 6.16/9 |

Table 2. Means of instrument constructs on a 9-point Likert scale

Grounded in the Motivational-Cognitive Learning Support model (Huang, Johnson, & Han, 2013), multiple regression analyses were conducted to reveal the relationships between learners' perceived cognitive loads and motivational support where cognitive loads are the dependent variables (intrinsic, extraneous, and germane loads) and the motivational support components are contributing variables with **the exclusion of Satisfaction**. The analyses yielded three significant models:

1. Intrinsic Cognitive Load (ICL)= Constant + Attention + Relevance*+ Confidence* ($R^2 = .15$, $F(3,106)=6.09$, $p < .01$) where Relevance significantly predicted ICL ($\beta = .52$, $p < .05$) and Confidence significantly predicted ICL ($\beta = -.57$, $p < .05$).
2. Extraneous Cognitive Load (ECL)= Constant + Attention* + Relevance + Confidence* ($R^2 = .53$, $F(3,106)=38.47$, $p < .01$) where Attention significantly predicted ECL ($\beta = -.22$, $p < .05$) and Confidence significantly predicted ECL ($\beta = -.72$, $p < .05$).
3. Germane Cognitive Load (GCL)= Constant + Attention + Relevance*+ Confidence ($R^2 = .31$, $F(3,106)=15.28$, $p < .01$) where Relevance significantly predicted GCL ($\beta = .99$, $p < .05$).

Discussion and Recommendations

Overall our findings supported the theoretical and empirical evidences on cognitive load-studies. In terms of intrinsic cognitive load, motivational components contributes the least amount to ICL's variance. This echoes the nature of ICL that is not as malleable by motivational design. In terms of extraneous load (ECL), both Attention that deals with multimedia representations and Confidence that deals with the easiness of carrying out intended learning tasks were found to be significant contributors. This finding largely aligns with design principles to reduce perceived ECL. Finally, the germane cognitive load (GCL) is only associated with the Relevance component of motivational support, which is mainly for learners to access their long-term memory in order to make sense of the learning tasks. The implication of the study is twofold. First, our findings identified significant relationships between motivational components as contributing variables and cognitive loads as outcome variables, which elevates the role of motivational design in supporting efficient cognitive learning processes in game-based VR learning environments. Second, our findings empirically suggest the possibilities of applying one design activity might impact learners' both motivational processing and cognitive processing, which speaks to the design efficiencies as well as their unintended consequences.

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