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Visual signaling in virtual world-based assessments: The *SAVE Science* project

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ABSTRACT

In this paper we describe a study into the impact of visual signaling techniques used in a virtual world-based assessment of science inquiry and content on (1) student cognitive load and (2) assessment efficiency. The study, run with 7th grade students in the United States, found that use of visual signaling was significantly associated with lower levels of student self-reported cognitive load versus students in a no-signaling version of the assessment. Further, the efficiency of the virtual world-based assessment was significantly higher, as measured by in-world object interaction rates, for students in the visual signaling version of the assessment than for those in the no-signaling treatment. In the paper, we discuss the results and their meaning for the design of virtual world and game-based assessments.

1. Introduction

The burden of assessment in the United States centers on standardized tests. Unfortunately, these tests frequently do not give a full picture of what students know about the complexity of science [39]. Research indicates that students tend to pass science tests, but often are not able to understand larger concepts, which typically are not assessed on multiple-choice tests [20]. Indeed, students are often assessed on whether they understand isolated vocabulary words such as “hypothesis”, while in-depth assessment of their abilities to formulate hypotheses and design experiments is neglected [24]. Further, a Carnegie report [3] suggests that the current testing system in the United States focuses heavily on assessing knowledge and interpretation to the detriment of scientific inquiry topics.

In an attempt to address these challenges, a growing number of researchers are turning to immersive virtual environments (IVEs). These game-like virtual worlds are able to situate science inquiry and content problems in authentic contexts for students to solve (e.g. [2,29,26]. Research is emerging on the question of how well IVEs can be used as a viable platform for science assessments. By following a systematic, theory-based approach to designing curricula and the activities of learning within those curricula, IVEs can produce data from students that more fully and validly demonstrate their evolving levels of competency around science inquiry and concepts [28]. Well-designed IVE-based assessments produce a steady stream of data to students and teachers, giving both groups new insights into student understanding and application of inquiry and content over time [35,27]. For example, Shute et al. [35] explore the idea of conjoining game-based IVEs with embedded assessments to create what they label “stealth” formative assessments. Shute and her colleagues argue that player interactions in an IVE can be assessed in real-time using probability analysis techniques. Students can be continuously and invisibly assessed as they work through series of challenging tasks situated seamlessly into game play and narrative [5]. The sum of

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these interactions over the course of an assessment adds up to meaningful evidentiary records of understanding of the content and processes taught in the IVE.

1.1. SAVE Science

SAVE Science is a 5-year study funded by the National Science Foundation centered on creating and evaluating an innovative IVE-based system for assessment of learning in science. *SAVE Science* is designing and implementing a series of virtual environment modules for assessing both science content and inquiry in 7th and 8th grades. The modules make use of a novel assessment rubric based on student interactions within an authentic context-based science curriculum, embedded in a virtual environment. We hypothesize that doing so will enable us to capture and analyze different patterns of scientific understanding amongst the students in a classroom. During the first 4 years of the *SAVE Science* project, we have designed four assessment modules, two introductory modules, and a dashboard for teachers and researchers that puts teachers in charge of student sign-up and gives them access to their students' data. Results from implementations with approximately 2000 students, 15 teachers at 12 schools indicate that *SAVE Science* assessments:

- Provide valuable information about misconceptions students have about specific science ideas, even after having studied them in class [11].
- Offer useful information for teachers that they cannot see through traditional testing methods [25].
- Offer contextual clues that aid students in applying their content learning in solving problems [12].
- Provide opportunities for students to "feel present" in the IVE, raising engagement and opportunities to show evidence of learning [34].

A major sub-focus of *SAVE Science* centers on conducting controlled and exploratory studies to investigate design approaches aimed at helping students manage the high cognitive load experienced while conducting assessment activities embedded in virtual environments. By reducing the perceived complexity of IVE-based assessments, we hypothesize that students will be better able to attend to the processes and tasks associated with the assessments, leading to more accurate assessment evidentiary data. To explore this hypothesis, we are investigating the use of design principles drawn from cognitive processing literature shown to support learning in presentational multimedia learning environments [25].

In this paper, we present the results from a quasi-experimental study into the use of the signaling principle in designing IVE-based assessments. This principle states that people learn better when the design of multimedia materials employs visual or auditory cues that highlight the organization of essential material to be learned [18,31,32]. This is accomplished in part by reducing the extraneous cognitive load learners are thought to experience when such signals are used and by directing the learner to important material. For example, Rey [33] found that college students ($N = 113$) who received instruction enhanced by visual signals outperformed those who received instruction without signaling, with higher retention scores (Cohen's $d = .04$) and statistically significant higher transfer scores ($F(1, 109) = 4.61$, $p < .05$; Cohen's $d = .41$). Another application of the signaling principle explored by Moreno et al. (2001) [21] was the use of an animated arrow or the deictic movements of a pedagogical agent compared to a control group with no signaling prompts. They found that both signaling conditions outperformed the control condition, with the pedagogical agent signaling group experiencing higher posttest scores ($p = .002$).

To explore whether the signaling principle can have a similar effect when applied to the design of an immersive virtual world, we conducted a study with middle school students in which we focused on the use of visual signaling techniques to reduce **perceived student cognitive load** in the *SAVE Science* virtual world while simultaneously increasing the number of times students click on or collide with assessment-relevant objects in the virtual world (**assessment efficiency**).

2. Theory

2.1. Cognitive load theory and signaling

Cognitive load theory [41] is based on the assumptions that working memory has a limited capacity, that learning is the process of storing information in long-term memory in the form of schemas, that these schemas automate the process of retrieving and responding to information, and that learning requires active cognitive processing. Cognitive load refers to the cognitive demands or mental effort a given task imposes on the learner. Sweller et al. [42] break down cognitive load into three types, or what they term the consequences, of cognitive load: intrinsic load, extrinsic load, and germane load. Intrinsic load is the cognitive demand inherent in the task itself, while extrinsic load are the demands imposed by the learning environment itself, e.g.: extraneous or irrelevant information. Germane load [42] is cognitive load that is associated with processing information, constructing schema, and developing automation of skills. Germane cognitive load facilitates the achievement of an instructional goal by enhancing the processing of information or aiding in schema construction. One of the goals of effective instructional design is to increase germane load while reducing extrinsic load.

According to Sweller [40] cognitive load is present when there is a high level of element interactivity, intrinsically and extrinsically. The intrinsic element interactivity refers to the amount of information that a student must understand in order