

Immersive Simulation on Collaborative Learning about a Complex Dynamic System

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Abstract: This mixed methods study examined the effect of Astronaut Challenge, an immersive, flight-simulation-based learning program, on the collaborative learning process and science knowledge development of high-school students (9th graders). The study findings suggested that simulation-based collaborative learning activities promoted students' scientific understanding about the dynamics of the space flight system. Although the knowledge test results did not indicate a significant differential effect of the two immersive settings (exclusive space versus classroom flight simulator) on the learning outcome, qualitative findings suggested that the higher level of the sensory immersion in a simulation-based learning environment may foster engagement while impeding collaborative conceptual understanding.

Keywords: science learning, flight simulator, computer supported collaborative learning, simulation environment design

Introduction

Immersion is a salient feature of the simulation-based learning environment. According to Dede (2009), immersion refers to “the subjective impression that one is participating in a comprehensive, realistic experience” (p. 66). It can be interpreted as a psychological experience that one perceives regarding how much s/he is attached to a learning environment, which can be provided via an active and dynamic interaction between the learner and their environment, sensory information in the 3D digital space, and authentic scenarios or tasks that tap into the learner's life experiences (Baños et al., 2004; Dede, 2009; De Freitas, Rebolledo-Mendez, Liarokapis, Magoulas, & Poulouvassilis, 2010). Studies have shown that immersive digital simulations, delivered via a computer-assisted simulator or a virtual reality, can enhance education by allowing multiple perspectives, situated learning, and transfer (e.g., Dunleavy, Dede, & Mitchell, 2009; Freitas & Neumann, 2009; Hansen, 2008). However, research on the effects of immersion on collaborative learning among students with diverse characteristics is still limited and inconclusive. Research is also needed on the learning strengths and preferences that the different levels of immersion in the digital space of a simulation cultivate in a diverse learner group, and hence the instructional arrangement of interactive media in a simulation-based collaborative learning environment.

Prior research suggested that immersive, participatory simulation is an emerging and prominent learning platform to help learners understand a complex, dynamic science system (Colella, 2000; Barab & Dede, 2007). Learning about complex systems is difficult because complex systems aggregate multiple components that interact with each other in multiple levels (Hmelo-Silver & Azevedo, 2006). Serman (1994) argued that approaches to learning about complex dynamic systems require tools to frame issues and elicit/create an iterative feedback-based learning cycle, and methods to improve group or team processes that will overcome defensive routines for individuals and sharpen scientific reasoning skills. Based on such a perspective, it is warranted to examine the capabilities of digital immersive simulations in promoting collaborative learning and hence understanding about a complex, dynamic system (such as the engineering system of a space flight).

Therefore, in this study we examined the design and effect of an immersive, simulation-based science learning program on the collaborative learning process and science knowledge development of high-school students (9th graders). The major research question are: (a) What are the impact of a space flight simulator program on high school students' collaborative learning processes and their science knowledge development? (b) Is there a differential effect of the immersive settings of this simulation-based learning environment on the collaborative learning process and outcome?

Methods

The study used a concurrent, mixed-method research approach (Clark & Creswell, 2011) to examine the immersive environment design and effect of a simulation-based science learning program. Student Astronaut Challenge, integrating a space flight simulator and a student manual on the basics of aerospace science, was the intervention program designed to promote collaborative, scientific discovery learning.

Participants

Twenty 9-10th graders were recruited from the General Earth Space Science classes of a local high school to participate in an after-school, Student Astronaut Challenge program. Among the program participants, 50% were girls, and 45% were learning disadvantaged (e.g., at-risk to not graduate) or had special learning needs (e.g., English language learning or medical accommodation). Participants were randomly assigned to two simulation conditions: exclusive space flight simulator condition (n=10, in two project teams) and classroom flight simulator condition (n=10, in two project teams). The wait-list students from the same classes formed a control group (n=22). The procedure, immersive simulation design, and simulation-based collaborative learning activities are outlined below.

Procedure

This current study lasted 4 weeks. At the beginning of the first week, all study participants received a pre-test on science knowledge. They were then given the Astronaut Challenge student manual to study during their weekly earth space science class and on their own at their convenient time and space. Participants of two simulation conditions also trained on space flight procedure one hour a week after school, from week 1 to week 4. Classroom simulator participants trained on the laptop-based space flight simulation, whereas exclusive space simulator participants trained on a physical space flight simulator. At the end of the fourth week, all participants received a posttest on the science knowledge. Each simulation project team also received a 30-minute, semi-structured group interview.

Immersive simulation setting

The space flight simulation encompasses the following components to provide the computer-generated immersion for the program participants:

- **Orbiter space flight simulation:** Based on the freeware space flight simulator Orbiter, a 3D flight simulation of the launch, flight, and landing of the Space Shuttle Atlantis was developed and used to enable simulated space shuttle operation and deliver sensory inputs/outputs.
- **PowerPoint multi-function display presentations:** PowerPoint presentations, pre-timed with the orbiter program to run concurrently, were used to simulate the data displays (known as multi-function displays) on the Space Shuttle. They were also used to enable the simulation of emergent situations and mission control of the space flight.
- **Shuttle switch control panels:** Four switch control panel templates were used to simulate the location of switches or control systems that must be turned on and off by the Mission Commander and Pilot during the flight.
- **Flight operational and emergency procedure checklists:** Pre-flight, in-flight, landing, and emergency procedure checklists, taken and customized from the actual ones used by space shuttle astronauts, were included as job aides for flight operations and emergency managements during flight.
- **Exclusive Space Flight Simulator versus Classroom Space Flight Simulator:** In the Exclusive Space Flight Simulator, a regular RV truck was customized to simulate a realistic space flight simulator. The physical set up, including display monitors, seats for the flight crew members, communication devices, and control panels, tried to artificially recreate the exclusive environment of a space flight. In comparison, the Classroom Space Flight Simulator was set up in a regular school classroom. Four desk computers, one overhead monitor, one computer joystick, and two radio control panels, along with regular classroom desks and chairs, were used to clone the functional setting of the space flight simulator. It is speculated that the exclusive simulator presents a higher sensory immersion than the classroom simulator.

Simulation-based collaborative learning activities

In both simulation conditions, participants were assigned into five-person teams, with each team being heterogeneous in terms of gender, ethnicity, and prior knowledge level. Each team consisted of a mission commander, pilot, mission specialist, and two mission control personnel. The initial positions in the team were randomly assigned among team members and eventually these positions were rotated between the teammates, allowing everyone to try multiple areas of responsibility. The students in each team would then practice as a group flying the space flight simulator using the procedure and emergency situation checklists. The flight operation involved normal operation controls (e.g., launching, flying, and landing) at first, and then problem solving in managing varied technical emergency situations. Successful operation of the space flight simulator

requires all astronauts to work together effectively, practice their individual jobs, and be aware of the jobs and responsibilities of the rest of the crew. Communication and collaborative operations among team members are essential, and the strict control of who speaks or does at what time and to whom is critical. The communication varied in its purposes (e.g., advises, announcements, or requests on status information), and required all members to swiftly identify what their responsibilities are, who they want to speak to, and what they need to know or report. This relationship is especially important when emergencies occur, therefore consistent practice together is necessary for an effective team.

Data collection and analysis

Data in this mixed methods study were collected via both quantitative knowledge test and qualitative infield observation and interview. The science knowledge tests were developed based on the test items used in the Astronaut Challenge program of previous years. Pre- and post-program knowledge tests were analyzed using descriptive and inferential statistics. Specifically, mixed design ANOVAs were conducted to examine the potential impact of the simulation-based science learning program on participants' science knowledge test performance, with time of the measurement as the within-subjects factor and study conditions (e.g., treatment vs control, and types of the simulator) as the between-subjects factor.

Participants' collaborative learning activities during program sessions were observed and video recorded. A semi-structured, focus group interview was then conducted with each project team after the program activities. Interviews, classroom observations, and video recordings were transcribed and imported into qualitative data analysis software. The qualitative coding was descriptive in nature, while focusing on understanding when, how, why, and with whom a simulation-based collaborative learning event occurred. We also conducted *categorical aggregation analysis* (Clark & Creswell, 2011) with the recorded and observed team activities, by coding the critical properties of meaningful actions or instances of simulation-based collaborative learning and classifying them into aggregations. Peer debriefing were conducted among the two coders and member checking were performed with the participants during the interview process. Finally, we sought meaningful patterns among the categories and synthesizing naturalistic conditions and consequences of the major categories. These patterns were then consolidated with quantitative findings.

Findings

The mixed ANOVA test examining the effect of the simulation-based science learning program indicated that there was a borderline significance in the interaction between the within-subjects factor and between-subjects factor on the knowledge test outcome, $F(1, 40) = 3.99, p = .06$, partial $\eta^2 = .17$. The test-performance change from the pretest to the posttest differed between the treatment group (simulation-based collaborative learning) and the control group, as shown by Figure 1 below. The control or no-simulation group's knowledge test performance were generally maintained from the pretest ($M_{precri} = 28.31$ $SD_{precri} = 5.41$) to the posttest ($M_{postcri} = 29.54$ $SD_{postcri} = 8.05$), whereas the treatment group knowledge test performance improved from the pretest ($M_{pretre} = 24.75$ $SD_{pretre} = 7.48$) to the posttest ($M_{posttre} = 33.50$ $SD_{posttre} = 6.72$).

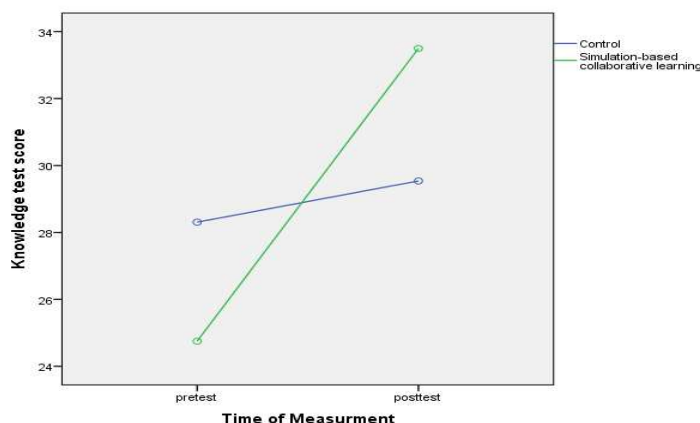


Figure 1. Pre-posttest performance by treatment condition

The mixed ANOVA test examining the differential effect of the immersive settings of the simulation environment (exclusive simulator vs. classroom simulator) on the science knowledge test did not indicate a significant interaction effect between the within-subjects and between-subjects factors. The result failed to

provide evidence for the learning effects of varied immersive settings of the simulation program. It should be noticed that the observed power for the interaction analysis was only .13, suggesting that the small sample size of each simulation group might have low statistical power to detect group differences. The test did indicate a significant main effect of the time factor ($p < .001$), confirming that both simulation-based collaborative learning groups significantly improved their knowledge test performance from the pre- to the posttest, $M_{\text{premsim}} = 22.5$, $SD_{\text{premsim}} = 9.57$, $M_{\text{postmsim}} = 32.25$, $SD_{\text{postmsim}} = 9.18$; $M_{\text{precsim}} = 27.00$, $SD_{\text{precsim}} = 5.03$, $M_{\text{postcsim}} = 34.75$, $SD_{\text{postcsim}} = 4.11$.

Two salient themes emerged from the qualitative data and shed light on the aforementioned trends: (a) communication-action-embodied meaning making, and (b) joint feedback process. It was found that collective and raced flight operation, requiring a shared understanding and a swift enactment of the space flight communication protocol and flight-control procedures, have enforced both conceptual and procedural knowledge practice and construction. Flight communications among the flight personnel and mission control, in either “advices”, “announcements,” “responses,” or “confirmations,” were filled with the externalization and constant monitoring of the shared understanding of a variety of complicated system concepts (e.g., Reaction Control System or RCS, hydraulics). Frequently, flight crew members were required to both verbalize and embody these concepts during the shuttle operations, “APU/HYDRAULICS (1/2/3) to OFF” (accompanied by the hand movement of turning off the corresponding buttons in the control panel). These conceptual verbalization and enactments would receive instant feedback via both naturalistic, visual/audio output of the computer system and the verbal confirmation/response from their teammates (e.g., “APU/HYDRAULICS 1/2/3 to OFF Check!”). In other terms, the simulated flight communication and collaborative shuttle operation has created the joint, feedback-based learning loop in which students would collaboratively and iteratively practice, observe, and act on domain-specific concepts and procedures.

Notably, we found that the sensory or physical immersion of a simulation setting might have fostered learners’ engagement in the procedural routine practice, while imposing impediments or distractions toward the feedback reflection and discussion for a deep conceptual understanding. In the exclusive space flight simulator, the simulated sound effects were loud and the area was restricted, thus making beyond-routine team debriefing and peer mentoring difficult. In comparison, the teams in the classroom simulator were found to be less contested by the sense of emergency, involved in more reciprocal questioning and answering, and obviously involved in more exploration and peer tutoring to achieve a better understanding, rather than memorization, of system concepts.

Conclusions and implications

The study findings suggested that immersive-simulation-based collaborative learning promotes students’ learning about the dynamics of the space flight system. Although the knowledge test results did not indicate a significant differential effect of the two immersive settings on the learning outcome, qualitative findings suggested that the higher level of sensory immersion may foster engagement while impeding collaborative conceptual understanding.

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