NSF IUSE
2215157

Interactive Virtual Labs for Teaching Evolution and Behavior

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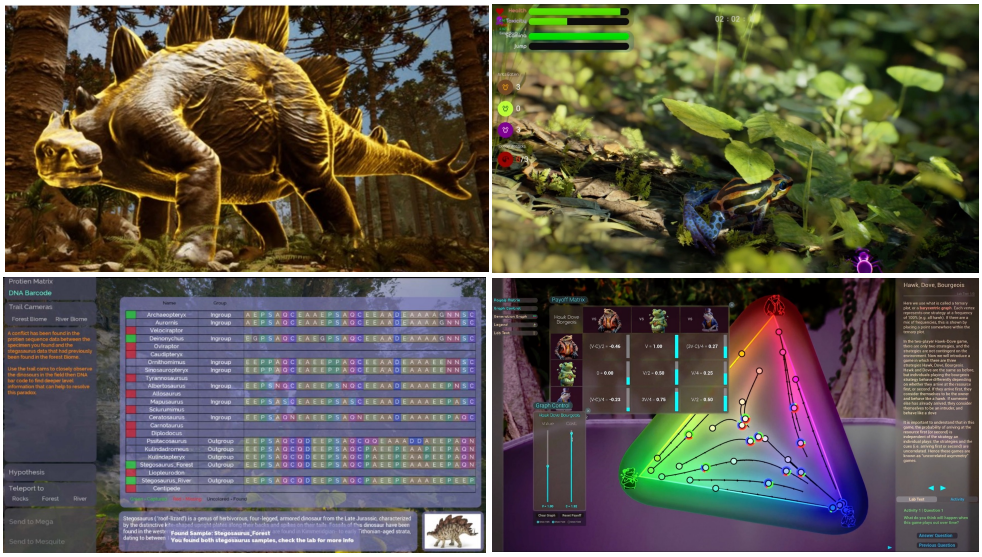

Figure 1. Upper left: Virtual dinosaur (Stegosaurus) in the Dinosaur lab. The dinosaur glows when students obtain data. Lower left: Aligned protein sequences from different species of dinosaurs. Upper right: virtual poison frog in the rainforest from the Frog lab. Lower right: Graphs showing assumptions and evolutionary trajectories (derived from game theoretic analyses) in the third phase of the Frog lab. Note that students have the ability to change the assumptions to learn about their effects on evolutionary trajectories.

Overview

- **Immersive, interactive computer labs created by *Almost Human Media*, in collaboration with PIs**
- **Lab 1: Evolution (Phylogenetics)**
- **Lab 2: Behavior (Predator-Prey)**

Our goal was to create interactive games to engage student's participation and interest, enhancing their understanding of course-related material. Almost Human Media, (project subcontractors) developed the interactive virtual computer labs in collaboration with the PIs. We implemented them in two courses: evolutionary biology, and behavioral ecology. In the Dinosaur Lab (Fig. 1: left panels) students visit a Jurassic-era forest, find various species of dinosaurs, and obtain key types of data (e.g. DNA sequences). These data are then used to reconstruct phylogenetic (evolutionary) relationships and carry out comparative analyses. The Frog Lab (Fig. 1) allows students to explore concepts related to the evolution of warning coloration and toxicity in the context of predator-prey interactions. Students play as poison frogs (toxic prey), then birds (predators) in the rainforest. In a third phase of the game, students explore the relevance of game theory to resource competition, using a graphical interface to manipulate the costs and benefits associated with the interactions of specific tactics (e.g. "hawk" vs. "dove"), and visualize what happens to the tactics and associated strategies across generations at the population level. Pre- and post-lab tests combined with experimental versus control lab comparisons were used to assess whether the labs improved subject knowledge and understanding, and whether the new labs compared favorably to an established virtual lab (from SimBio Inc.) covering similar material. Qualtrics surveys were used to evaluate student responses to both types of labs (treatment and control) for both disciplines.

Results & Discussion

- **Both labs: significant improvements in test scores after lab (paired t-tests)**
- **Evolution (Dinosaur) Lab: significant improvements in test scores relative to control lab (unpaired t-test)**
- **Behavior (Frog) Lab: trend toward higher test scores relative to control lab ($p = 0.068$, unpaired t-test)**
- **Comments on the new labs from students on Qualtrics surveys were overwhelmingly positive, and showed a preference for the new labs**
- **Sample comments:**
- ***"I thought it was very exciting and realistic. I have never had a lab like this. (Dinosaur Lab)"***
- ***"Yes! It was so interesting to learn in a POV (point-of-a-view) type of way. I have never learned material this way and I believe that it was so much more helpful to learn the topic this way. (Frog lab)"***
- **Students particularly liked the gameplay, the ability to manipulate and test variables, and the combination of gameplay, graphics, and the realistic feel of immersion in the virtual world provided by the new labs**

Paleosaurus lab: Students completing both labs (treatment and control) showed significant improvements in their scores (paired t-tests, treatment pre-test average score ($\bar{X}$ = 26.5%, SE = 5.6%) vs. post-test ($\bar{X}$ = 71.4%, SE = 6.6%), $p < 0.0002$, control pre-test average score ($\bar{X}$ = 10.6%, SE = 4.1%) vs. post-test ($\bar{X}$ = 36.8%, SE = 7.5%), $p < 0.008$). No significant difference was found between student scores for the Paleosaurus (treatment) and SimBio (control) lab pre-tests (unpaired t-test, $p = 0.147$). Comparisons of the post-lab test scores on the five general questions on phylogenetics (questions 1-5) showed significantly higher scores for the Dinosaur Lab (treatment) students ($\bar{X}$ = 71.4%, SE = 6.6%), compared to the SimBio lab (control) students ($\bar{X}$ = 36.8%, SE = 7.5%), unpaired t-test, $p < 0.008$. Comparison of the post-lab test scores across all ten post-lab test questions (general and lab-specific questions) showed significantly higher scores for the Dinosaur Lab (treatment) students ($\bar{X}$ = 59.6%, SE = 5.1%) compared to the SimBio lab (control) students ($\bar{X}$ = 36.8%, SE = 7.5%), unpaired t-test, $p < 0.02$. Note that unpaired t-tests assuming equal variances were used, F-tests were performed to compare variances, and no significant differences were found ($p > 0.1$ for all tests). Frog lab: Students completing both labs (treatment and control) showed significant improvements in their scores (treatment pre-test score $\bar{X}$ = 17%, SE = 5.6%, post-test score $\bar{X}$ = 65.3%, SE = 9.5%, control pre-test score $\bar{X}$ = 5.3%, SE = 1.9%, paired t-tests, Pre-test vs. Post-test, $p < 0.03$ (treatment), $p < 0.004$ (control). Students doing the Frog lab had higher average post-lab scores than students completing the SimBio Lab, but the difference was not statistically significant (treatment $\bar{X}$ = 70%, SE = 7.9%, control $\bar{X}$ = 42%, SE = 7.2%, unpaired t-test, $p = 0.068$). No significant differences were found for the pre-test scores. Note that unpaired t-tests assuming equal variances were used, F-tests were performed to compare variances, and no significant differences were found ($p > 0.54$ for post-tests, $p > 0.11$ for pre-tests). Results from the Qualtrics surveys indicated that students had overwhelmingly positive responses to the labs (an approximately 10:1 ratio of positive to negative comments), and they indicated a preference for the new labs over the control labs. They particularly liked the gameplay experience, the ability to manipulate and test variables, and the combination of gameplay, graphics and the realistic feel of immersion in a virtual world provided by the new labs.

These new labs compare favorably, in terms of learning outcomes, to commercial virtual labs. They have an advantage over control virtual labs used for science education in that they implement advanced computer simulations and graphics, providing an immersive and highly interactive experience found in sophisticated commercial computer games, but not typically found in currently available computer labs used for science education in undergraduate courses. In terms of broader impacts, we think this kind of virtual lab could be of value in engaging students with course material and stimulating them to explore key concepts in detail, leading to more effective learning and retention.

Methods

- **Undergraduate volunteers from two courses: evolution and behavioral ecology**
- **Pre- vs. post-lab test comparisons of content knowledge**
- **Comparisons of post-lab knowledge between commercial virtual labs (controls) and the new labs (treatments)**
- **Qualtrics surveys of student experiences**

The computer labs were developed by *Almost Human Media* using photorealistic visual graphics and simulations to create highly interactive games, using the latest version of the *Unreal Engine* (Epic Games, Inc.). Advice relevant to content and assessment was provided by PI Summers and Co-PI Annetta during development. Assessment strategies focused on both pre- and post-lab tests after both treatment and control labs, and on survey data. Paleosaurus Lab comparisons: Students were assigned to treatment versus control labs using a random number generator implemented in Microsoft Excel. Students were given a pre-test with ten questions to test general knowledge of the topics covered in both labs (phylogenetics). Students were given post-tests to test improvements in knowledge of the topics covered in the labs. For both labs (Paleosaurus Lab: treatment group, N = 8 students, SimBio Trees and Flowers Lab, N=8 students), students were given a post-lab test with five general questions, and five lab-specific questions covering material specific to either the Paleosaurus Lab or the SimBio Trees and Flowers Lab (questions were of equivalent difficulty). Answers were graded on a percentage scale (0-100 percentage points for each answer). Statistical comparisons were done to compare average scores across questions associated with: 1) improvement (pre-test vs. post-test (5 questions) in each group), 2) treatment vs. control for post-test (5 general questions, 5 lab specific questions). FrogLab comparisons: Students were assigned to treatment versus control labs using a random number generator implemented in Microsoft Excel. Students were given a pre-test with five questions to test general knowledge of the topics covered in both labs (Game Theory and the Hawk-Dove game). Students were given a post-test to test improvements in knowledge of the topics covered in the labs. For both labs (Frog Lab: treatment group, N = 4 students, SimBio Lab, N=5 students), students were given a post-lab test with the original five questions, and four more questions covering material that overlapped between the SimBio lab and the Frog Lab (focused on game theory and the Hawk-Dove Game). Answers were graded on a percentage scale (0-100 percentage points for each answer). Statistical comparisons were done to compare: 1) improvement (pre-test vs. post-test (5 questions) in each group), 2) treatment vs. control for pre-test and post-test (pre-test = 5 questions, post-test = 9 questions, identical questions for each group). Unfortunately, pre-test results for two individuals in the control group were not recorded. These individuals were assigned the average value for both groups (a score of 10.2). Following the content posttest, students were asked to respond to targeted and open-ended questions through an online instrument in Qualtrics. The instrument asked questions specific to the virtual lab experience and allowed students an anonymous platform to provide honest feedback. Analyses were accomplished by dual coding for keywords in context (KWIC) through content analysis. This analysis looks for common words and its every utterance in textual responses to find a meaning and usage. This allows for understand the potential meaning of the work and how it was used by the respondent. First, categories were identified (themes), then descriptive findings (patterns) were identified. Themes and patterns were identified through inductive analysis. Member checks and a peer debriefing session confirmed dependability of findings. To strengthen the precision and validity of the overall themes. and patterns, a replication strategy was followed to determine whether the themes and patterns from each Lab held up in a comparable setting. Finally, open-ended responses were coded and inter-rater reliability was conducted to insure agreement. Near point agreement was reached at 100%. Results from the various closed-ended questions suggested positive aspects of participating in a virtual lab through simulated games. When asked about overall thoughts on the lab for which a student participated, responses were overwhelmingly positive. Every student participant responded that their experience was a unique and successful means of learning.