Randomized controlled trial captures conceptual change via a serious game in undergraduate molecular biology students

Andrea Gauthier, BAX, MSc(BioMed), PhD candidate, Vanier scholar
Jodie Jenkinson, PhD
Biomedical Communications, Institute of Medical Sciences, University of Toronto

ABSTRACT

Background: Undergraduate biology students often lack an understanding of the emergent nature of molecular environments, frequently attaching agency to molecular 1-2. Serious games might increase conceptual understanding of complex science by instigating instances of productive negativity 3-5. Misconceptions recorded on the Molecular Concepts Adaptive Assessment (MCAA) 7 reflect lack of conceptual understanding about the emergent nature of the molecular world (Figure 2). The presence of rules allowed for strategic interaction, resulting in high demonstrations of correct conceptual knowledge that were not indicative of immediate success, but which then prompted a demonstration of correct conceptual knowledge (Figure 3-B).

Objective: To characterize how game design facilitates conceptual change about molecular emergence above and beyond standard education and an interactive simulation without gaming elements (Figure 1).

Participants: First- (n = 292), second- (n = 209), and third- (n = 34) year undergraduate biology students. Baseline: n = 486; Control: n = 20; Game: n = 20.

Procedure: Molecular Concepts Adaptive Assessment completed at beginning and end of semester; game/control exposure with subset of participants for 30 minutes (recorded digitally) before post-test.

Results: Those exposed to the game (p < .001) and control (p < .007) reached more misconceptions than the baseline group. Gamers trended toward negative misconceptions than control users (p = .054) likely due to larger numbers of productively negative events facilitated through gameplay. For gamers, a relative relationship exists between the quality of productively negative experiences and misconceptions (p = .006).

Implications: Conceptual understanding about molecular emergence may be facilitated through gameplay integrating conceptual change strategies. Game interactions (specifically the quality of their productively negative experiences) might be used to predict conceptual understanding.

METHODS

Participants:
First-year BI0152 students (n = 20)
Introduction to Evolution and Molecular Genetics: Focus on organism diversity; molecular biology concepts are not covered as a topic in this course (novice learners).
Second-year BI0266 students (n = 20)
Introduction to Cell and Molecular Biology: Evolutionary biology, other cellular processes; these students represent the game’s primary target audience.
Third-year BI0372 students (n = 34)
Molecular Biology: More advanced concepts in molecular biology; represents an advanced learner group.

Molecular Concepts Adaptive Assessment (MCAA)

Example question to characterize misconception (agency): A molecule moves toward a cell membrane to bind the receptor, which the cell recognizes as a signal for immediate action (TRUE/FALSE) based on your previous answer and assuming there are several of the complementary receptors present, whichever complementary receptor is closest. The lack of rules allowed for random experimentation, resulting in high demonstrations of correct conceptual knowledge that were not indicative of immediate success, but which then prompted a demonstration of correct conceptual knowledge (Figure 3-B).

Methods

Participants
First-year BI0152 students (n = 20)
Introduction to Evolution and Molecular Genetics: Focus on organism diversity; molecular biology concepts are not covered as a topic in this course (novice learners).
Second-year BI0266 students (n = 20)
Introduction to Cell and Molecular Biology: Evolutionary biology, other cellular processes; these students represent the game’s primary target audience.
Third-year BI0372 students (n = 34)
Molecular Biology: More advanced concepts in molecular biology; represents an advanced learner group.

Molecular Concepts Adaptive Assessment (MCAA)

Example question to characterize misconception (agency): A molecule moves toward a cell membrane to bind the receptor, which the cell recognizes as a signal for immediate action (TRUE/FALSE) based on your previous answer and assuming there are several of the complementary receptors present, whichever complementary receptor is closest. The lack of rules allowed for random experimentation, resulting in high demonstrations of correct conceptual knowledge that were not indicative of immediate success, but which then prompted a demonstration of correct conceptual knowledge (Figure 3-B).

Results

Change in misconceptions from beginning to end of the semester

We performed a 3x3 repeated measures mixed model to determine how educational level (first-, second-, or third-year biology) and intervention type (no intervention, control simulation, or serious game) affected students’ molecular misconceptions from pre-test to post-test (Figure 2).

- Educational level did not have an effect on the change in misconceptions (F(4, 526) = 0.95, p = .435).
- Intervention type had a significant effect (F(4, 526) = 8.94, p < .001).
  - The control simulation was more effective than no intervention (p = .007, 95% CI = -2.62, -2.00).
  - The serious game was more effective than no intervention (p < .001, 95% CI = -4.25).
  - The serious game tended toward being more effective than the control simulation (p = .084, 95% CI = -2.98).
  - No significant interaction effect between the testing time, stimulus, or educational level.

Screencasts were coded for demonstrations of correct conceptual knowledge and instances of productive negativity:

- Demonstration of correct conceptual knowledge: series of actions wherein the user made appropriate adjustments to the simulation (i.e. in concentration, temperature, or crowding) in order to complete the objective at hand (Figure 3-A).
  - Instance of productive negativity: series of actions not indicative of a correct conception and that does not result in immediate success, but which then prompts a demonstration of correct conceptual knowledge (Figure 3-B).

Implications & Future directions

- Interaction with a simulated, molecular environment helps students resolve misconceptions about the emergent nature of the molecular world (Figure 2).
- The presence of game design (namely resource management, an immersed 3rd-person character, sequential level progression, scoring, and feedback) encourages greater numbers of productively negative experiences (Figure 3-B), the quality of which is associated with misconceptions (Figure 4, 5).
- While control-users appeared to have a higher quality of productively negative experiences (i.e. they generated more demonstrations of correct conceptual knowledge per instance of productive negativity reported), this was not associated with misconceptions (Figure 5).
- The lack of rules allowed for random experimentation, resulting in high demonstrations of correct conceptual knowledge that were not indicative of conceptual understanding.
- Future studies will investigate how long-term concept retention differs between intervention groups with different stimulus exposure times.

References