molWorlds

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

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Abstract

Background Undergraduate biology students often lack an understanding of the emergent nature of molecular environments, frequently attaching agency to molecules[1,2,3]. Serious games might increase conceptual understanding of complex science by instigating instances of productive negativity[4,5,6].

Purpose 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 (interactions recorded digitally) before post-test.

Results Those exposed to the game ($p < .001$) and control ($p = .007$) resolved more misconceptions than the baseline group. Gamers trended toward resolving more misconceptions than control-users ($p = .084$) likely due to larger numbers of productively negative events facilitated through gameplay. For gamers, a negative relationship exists between the quality of productively negative experiences and misconceptions ($p = .066$).

Implication 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 BIO152 students (n = 292)	Second-year BIO206 students (n = 209)	Third-year BIO372 students (n = 34)
Introduction to Evolution and Evolutionary Genetics Focus on organism diversity; molecular biology concepts are not covered as a topic in this course (novice learners)	**Introduction to Cell and Molecular Biology** Biology's Central Dogma, vesicular formation, other cellular processes; these students represent the game's primary target audience	**Molecular Biology** More advanced concepts in molecular biology; represents an advanced learner group

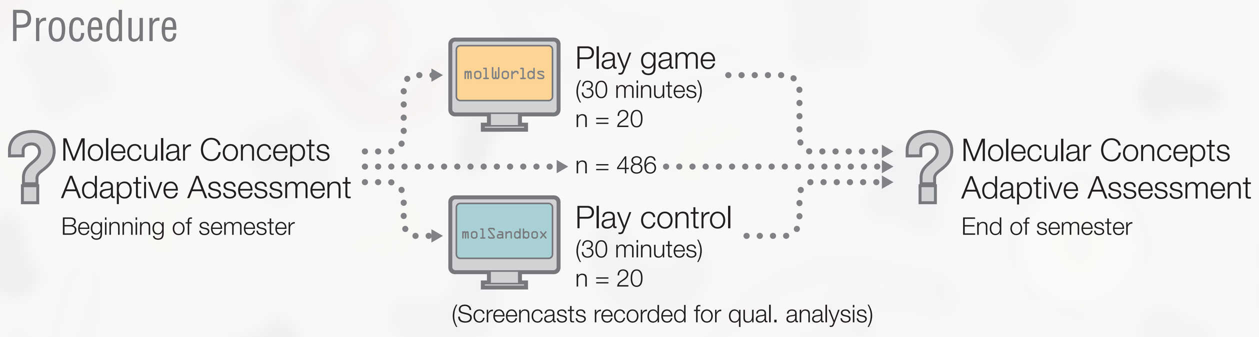
Molecular Concepts Adaptive Assessment (MCAA)[7]

Example question to characterize misconception (agency)

A) (TRUE/FALSE) An extracellular molecule tries to move toward a complementary receptor.

B) (if A=TRUE) Based on your previous answer and assuming there are several of the complementary receptors present, an extracellular molecule tries to move toward:
> one specific predetermined complementary receptor;
> any of the complementary receptors that are present;
> whichever complementary receptor is closest.

Procedure



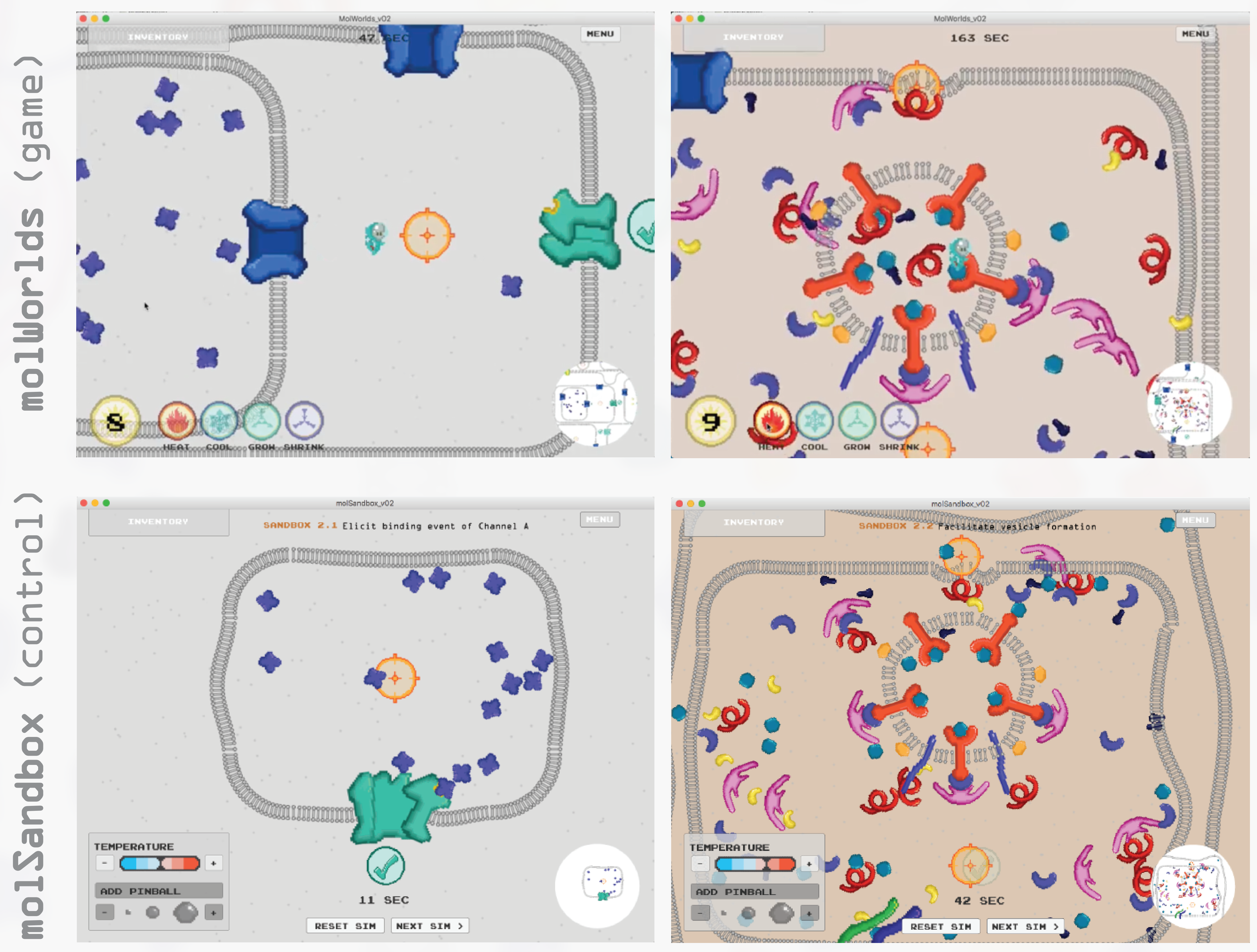
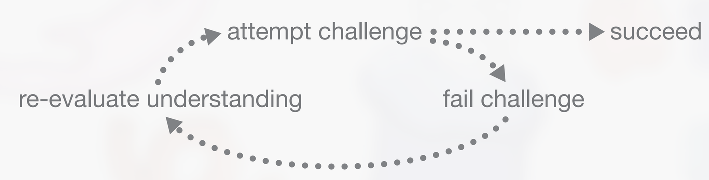


Figure 1. Screenshots comparing levels 6 (left) and 7 (right) in the game (*MolWorlds*) and the control (*MolSandbox*). *MolWorlds* incorporates game mechanics such as **resource management**, an **immersed 3rd-person character**, **sequential level progression**, **scoring and feedback** to enhance productively negative experiences.



The purpose of facilitating failure, irritation, or other negativity in a game is to promote reflection followed by actions that indicate a better understanding of the target concept in order to complete the game challenge[4].

Results

Change in molecular misconceptions from beginning to end of the semester

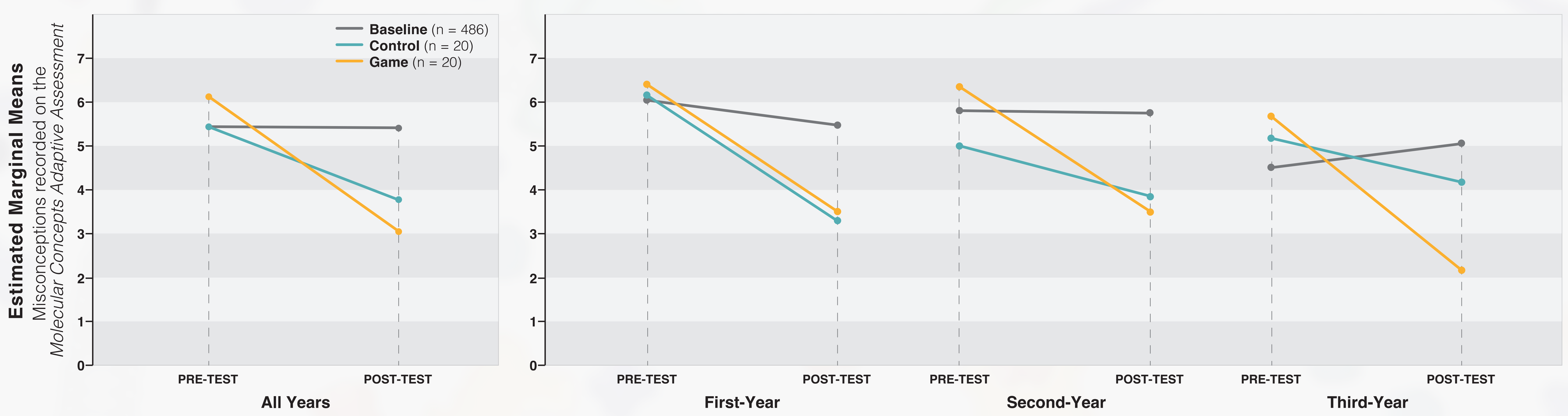


Figure 2. Estimated marginal mean misconceptions (lower scores represent better performance on the *MCAA*) from pre-test to post-test across intervention groups (baseline, control stimulus, or game stimulus) and by educational level (first-, second, or third-year biology), outputted from a 3x3 repeated measures mixed model analysis (using the "unstructured: correlation metric" repeated covariance type to compensate for unequal sample sizes)

- 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** DID have a significant effect ($F(4, 526) = 8.94$, $p < .001$)
    - The **control simulation** was more effective than **no intervention** ($p = .007$, 95% CI[-0.45, -2.82])
    - The **serious game** was more effective than **no intervention** ($p < .001$, 95% CI[-1.85, -4.23])
    - The **serious game** trended toward being more effective than the **control simulation** ($p = .084$, 95% CI[0.19, -2.99])
  > No significant interaction effect between the testing time, stimulus, or educational level ($F(8, 526) = 0.43$, $p = .903$), meaning that individuals from different years but who were exposed to the same stimulus changed in similar ways.
- 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).

Productive negativity and demonstrations of correct conceptual knowledge

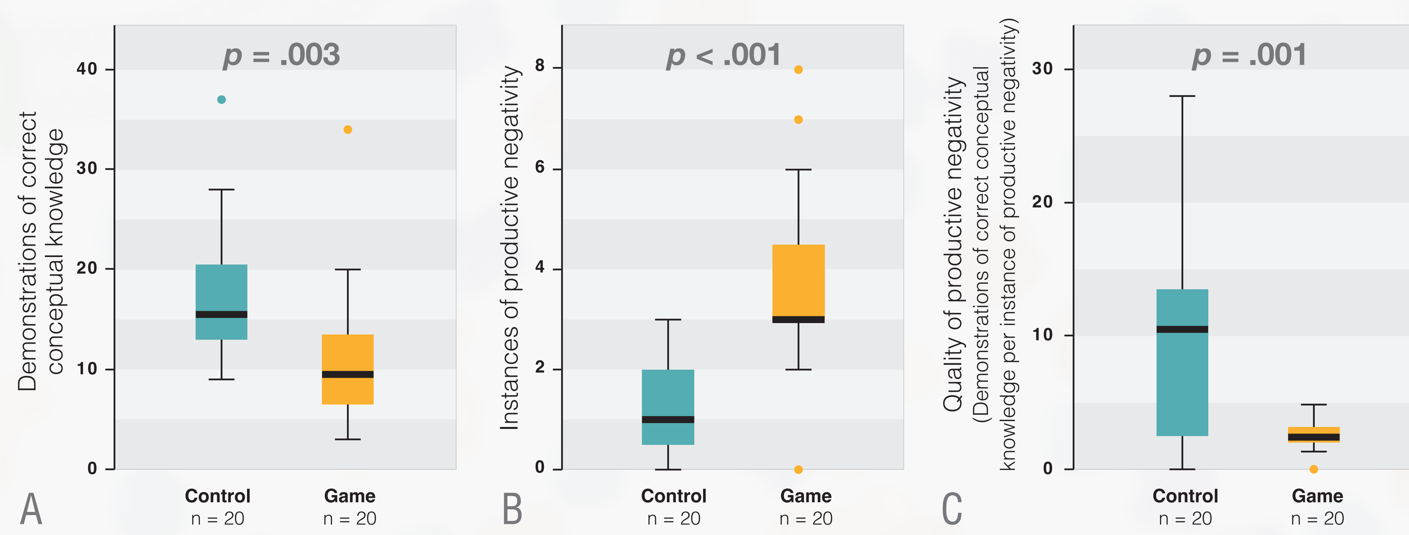
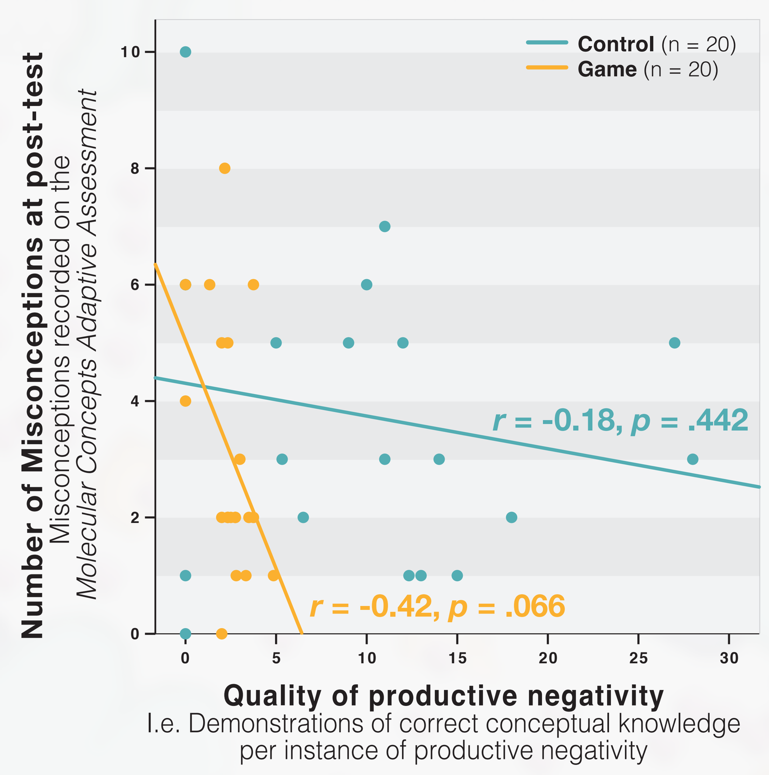


Figure 3. Box-plots showing the number of A) demonstrations of correct conceptual knowledge, B) instances of productive negativity, and C) the quality of productively negative experiences (i.e. A/B) elicited by the game and control applications. Results obtained through qualitative coding of video data.

Relationship between misconceptions and quality of productively negative experiences



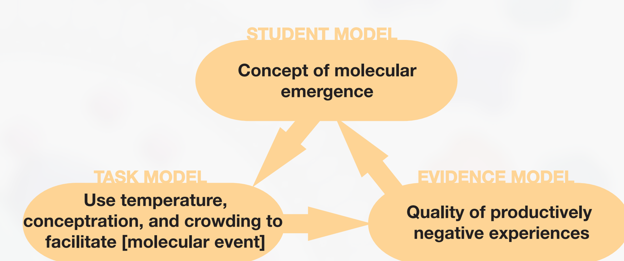


Figure 4 (above). Evidence-centred design framework[8] for *MolWorlds* for assessing conceptual knowledge. We should see a relationship between the quality of productively negative experiences elicited by gameplay and conceptual understanding.

Figure 5 (left). Relationship between quality of productively negative experiences and post-test misconceptions. A trending correlation exists in the game group, whereas no relationship exists in the control.

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 experienced; Figure 3-A), 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.

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