VISUALIZING the complexity of the molecular world

The role of animation in supporting understanding

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1 The Problem

Students experience difficulty understanding biological concepts as they involve numerous interacting processes occurring at multiple scales of time and space. Rather, students tend to approach biology as a series of unconnected ideas or theories, rarely integrating their knowledge and making a connection with real life phenomenon[1,2,3] Subject areas of particular difficulty for students include protein conformation and stability [4], diffusion and random molecular motion [5], and molecular crowding [6]

2 The Approach

In this study we examined the relative effectiveness of 3D visualization techniques for learning about molecular biology, specifically protein conformation and molecular motion in association with a cell-binding event. Increasingly complex versions of the same receptor-ligand binding event were depicted in each of 4 animated treatments (Figure 1). We were interested in understanding how different visual variables map to the students' performance on test questions that ranged from more straightforward fact-based to more abstract intuitions of protein behavior at the molecular scale.

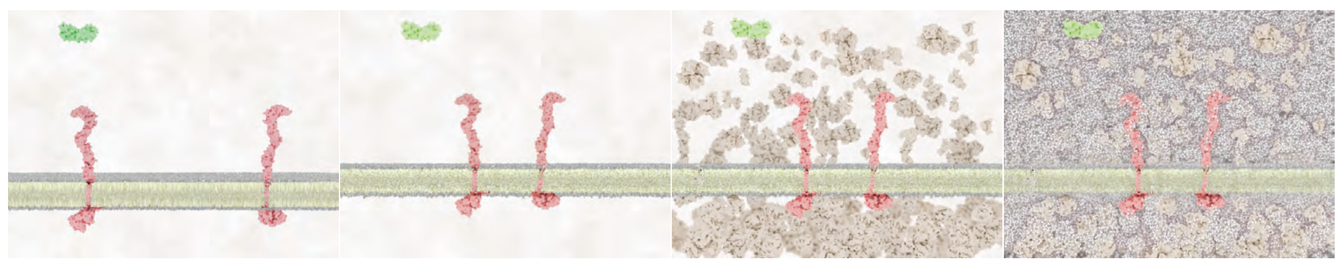


Figure 1. Stem cell factor (SCF) ligand and cKit receptor tyrosine kinase were used as a classical example of a ligand-induced receptor dimerization and activation event.

EXPERIMENT 1

Students (N = 131; Age = 18-24; 19 Year I, 52 Year II, 33 Year III, 27 Year IV) were recruited from the undergraduate Biology program at University of Toronto Mississauga. Each of three test instruments (Pre-test, Post-test, and Delayed Post-test) used in this study, included 10 short answer questions. Each test included questions to measure both students' surface level understanding and their deep level understanding.

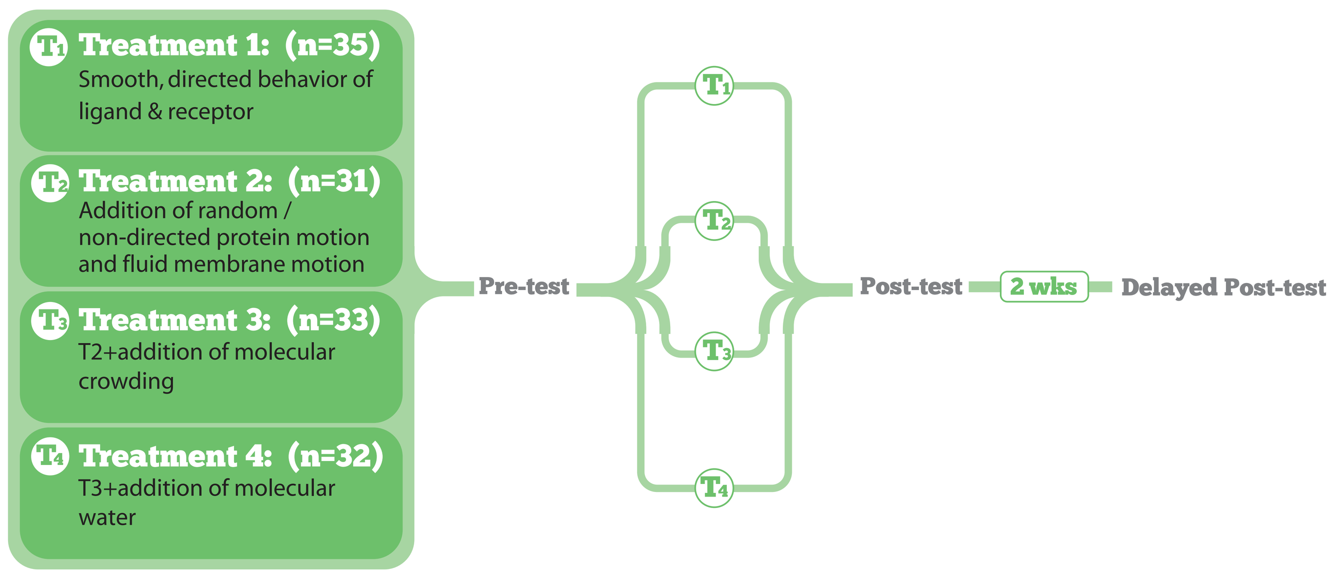
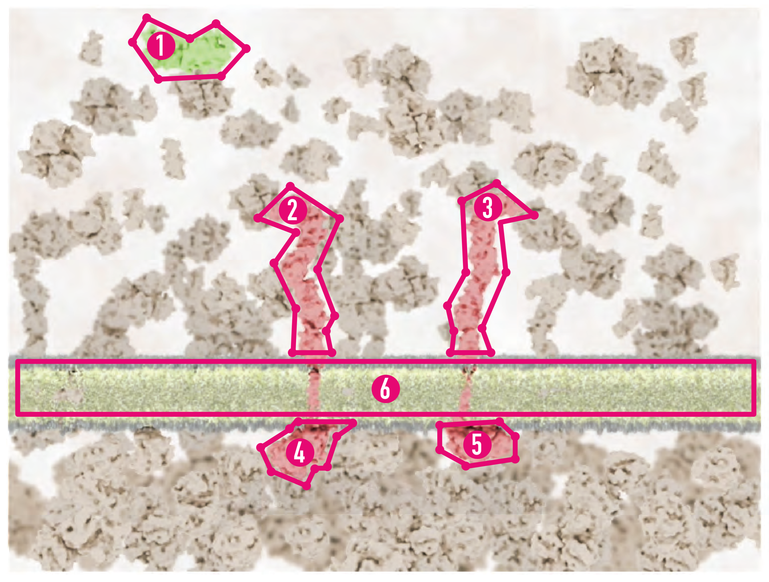


Figure 2. Experimental protocol for assessing the impact additive layering of visual variables upon students' understanding of a receptor-ligand binding event

EXPERIMENT 2

A second experiment (N=8) was conducted to characterize the learning that occurred with respect to each of the 4 versions of the animation viewed. In this scenario, students verbalized their thoughts while watching each of the animations (either in order, or reverse order). Concurrently, their eye movements were recorded. Verbal protocols were analyzed for understanding (statements were coded as descriptive and explanatory). In order to assess visual attention, corresponding dynamic areas of interest (AOIs) were established within each of the four animations and data was collected on the number of fixations within each AOI. Data collected throughout this experiment (test responses, verbal reports, and eye tracking videos) were analyzed comparatively; this served to triangulate the data and to help enhance the credibility of the findings and assertions made.



Areas of Interest

1. Stem cell factor
2. KIT-L ectodomain
3. KIT-R ectodomain
4. KIT-L endodomain
5. KIT-R endodomain
6. Cell membrane

Figure 3. Areas of Interest identified for the assessment of visual attention

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3 Findings

EXPERIMENT 1

A repeated-measures ANOVA was conducted to evaluate the relationship between treatment and knowledge over time. The results, summarized in the table below, show that test scores varied significantly between pre, post, and delayed post assessment (Wilk's $\Lambda = .665$, $F(2,126) = 31.74$, $p < .001$, multivariate $\eta 2 = .33$). Post Hoc analyses (one-way ANOVA) with a Bonferroni correction were conducted to identify differences between treatment groups at each time point (Table 1 and Figure 4).

Post-test					Delayed Post-test				
Group (I)	Group (J)	Mean (I-J)	Std. Error	Sig.	Group (I)	Group (J)	Mean (I-J)	Std. Error	Sig.
1	2	-.88	.479	.405	1	2	-1.10	.487	.154
	3	-1.66	.471	.004		3	-1.39	.479	.025
	4	-1.53	.475	.010		4	-1.49	.483	.015

Table 1. Post hoc comparisons of Post-test and Delayed Post-test results

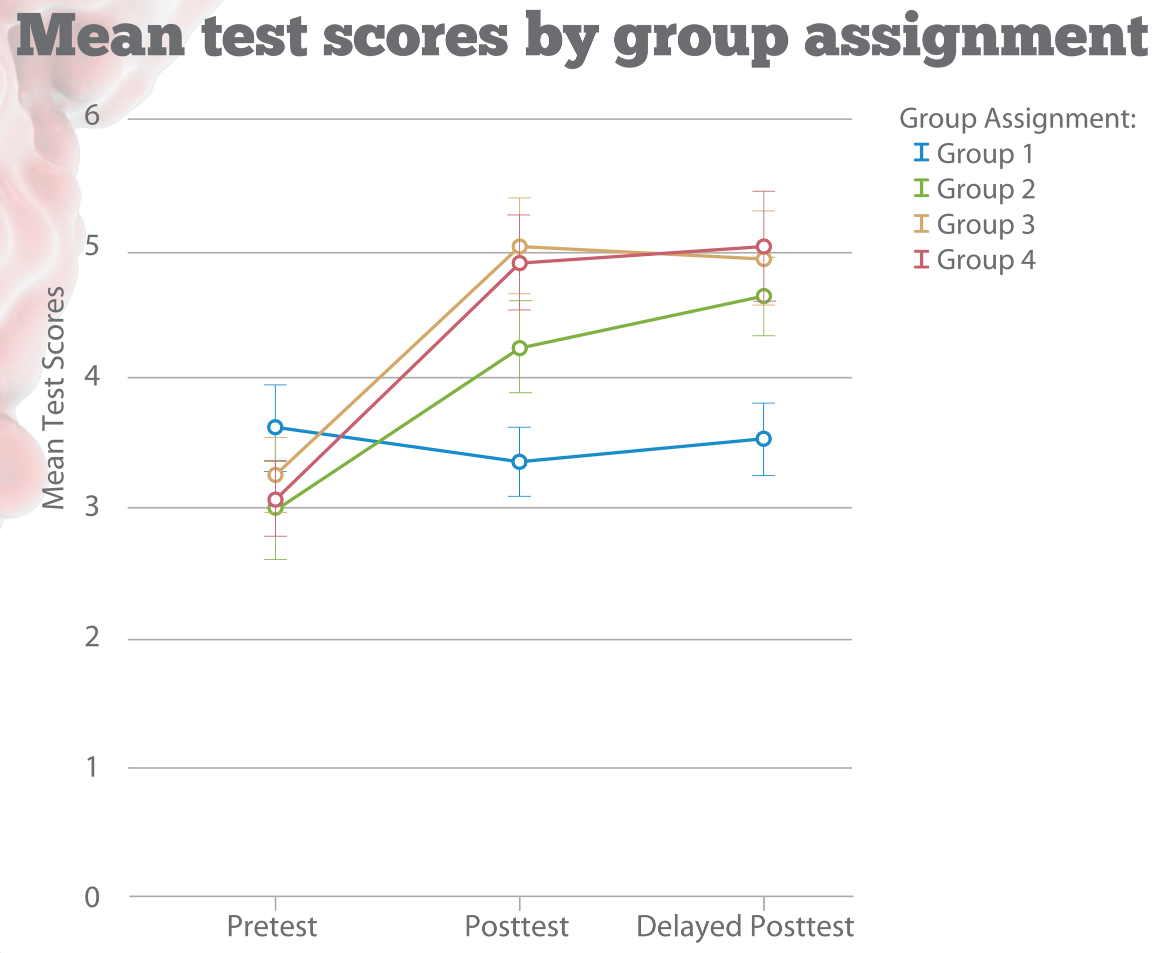

Figure 4. Plot showing group mean test scores at 3 time intervals

EXPERIMENT 2

Analysis of verbal reports and eye tracking data suggest that students are able to attend to the same narrative elements regardless of the level of complexity depicted in each animation. Analysis of verbal protocol data revealed a positive correlation ($r = .98$, $p < .05$) between the number of explanatory statements expressed by participants and the complexity of the animation viewed. As well, prior knowledge was positively correlated ($r = .81$, $p < .05$) with the number of explanatory statements contained in each protocol.

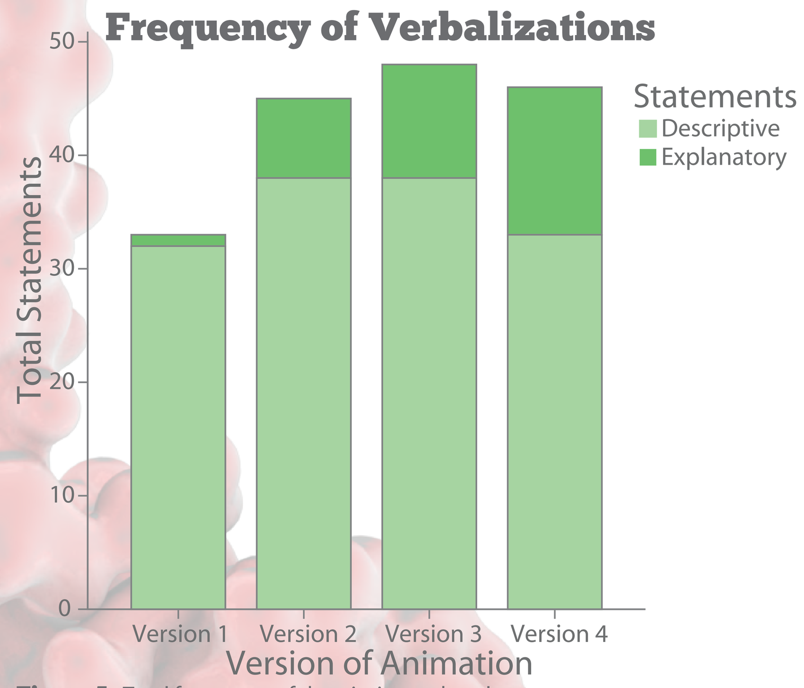

Figure 5. Total frequency of descriptive and explanatory statements

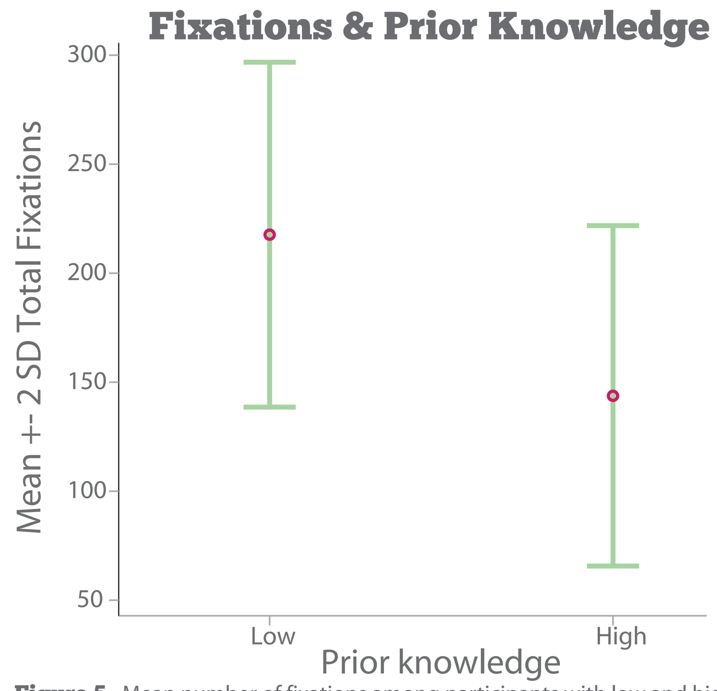

Figure 5. Mean number of fixations among participants with low and high prior knowledge

4 Implications

Our data show that with increasing levels of visual complexity students' overall performance improved significantly. Participants responses to basic questions were comparable at Post-test and significantly higher in Groups 3 and 4 on Delayed Post-test. Students assigned to Groups 3 and 4 scored significantly higher on advanced questions in the Post-test but not on the Delayed Post-test. In other words, the learning effects of the more complex visualizations were lasting, but only with regard to the more basic concepts. Results also suggest that students have difficulty understanding and associating randomness with molecular events. The verbal reports contained several instances of students' attaching agency to protein and ligand, anthropomorphizing their movements and subsequent binding. Additional attention must be given to exploring techniques that can satisfactorily balance the random nature of molecular events with narrative explanations of these processes.

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