IDT 500

Research Literature Review

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Fall 2021

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# Literature Review

## Introduction

This literature review contains the evaluation of six scholarly articles and their relevance to my applied evaluation project. The purpose of my research project is to examine the instructional strategies used in higher education biology and biochemistry that incorporate 3D animations and their studied effect on students’ motivation with, comprehension, and retention of complex processes required for these types of courses. To address this statement, I will investigate how these instructional strategies can affect student motivation with content involving complex processes, and I will evaluate research that suggests when these types of instructional strategies are more effective for improving student comprehension and retention of complex processes than other instructional strategies. The majority of articles critiqued in this review use quantitative data and statistical results to draw similar conclusions; students who view 3D animations of complex molecular processes outperform students who view simpler visuals instead. One article reviewed here collected only qualitative data by gathering students’ feedback after viewing an animation, offering insight as to how student motivation is affected by 3D animations.

## Research Article Critiques

### Variation in External Representations as Part of the Classroom Lecture: An Investigation of Virtual Cell Animations in Introductory Photosynthesis Instruction.

**Article Reference.** Goff, E. E., Reindl, K. M., Johnson, C., Mcclean, P., Offerdahl, E. G., Schroeder, N. L., & White, A. R. (2016). Variation in External Representations as Part of the Classroom Lecture: An Investigation of Virtual Cell Animations in Introductory Photosynthesis Instruction. *Biochemistry and Molecular Biology Education, 45*(3), 226-234. doi:10.1002/bmb.21032

**Research Query**. This article relates to my research question,

1) In higher education biology and biochemistry curricula, when are instructional strategies that incorporate 3D animations most effective for improving comprehension and retention of complex molecular processes?

**Abstract**. With the use of external representations (ER) becoming increasingly popular in undergraduate biology courses, the authors want to compare the two most common; static images and dynamic animations. Previous research has shown conflicting findings when comparing the two, but there have been benefits for each method. Particularly for biology though, it has been found that students struggle to understand and retain concepts that are complex and involve many procedural parts like photosynthesis, so the authors believe that a comparison of static images and dynamic animations for teaching such concepts may reveal the more effective method. In this article, they conduct a study on undergraduate students of a biology laboratory course where five of ten sections receive a lecture on photosynthesis that uses static graphics, while the other five sections receive the same lecture except with dynamic animations. The normalized gain scores collected from posttest results reveal that students who viewed the dynamic animation outperformed those who viewed the lecture with static images, suggesting that educators faced with teaching photosynthesis should turn to animations for more effective instruction.

**Research Questions/Hypotheses**. The hypothesis stated in this article is that in this study, students who view photosynthesis animations as part of lecture will exhibit greater normalized gain scores as compared to students who view static images as part of the lecture. The authors of this article have found that short-hand guides like arrows that are used to convey processes with static images may increase cognitive load, resulting inaccurate mental models and misconceptions of the content. Previous research that they have analyzed suggests that students may benefit from dynamic animations when learning complex processes that entail small details like electron transfer and concentration gradients. They believe that animations offer a better way to convey moving parts of a complex process, which improves immediate recall and concept retention over time.

**Description of Sample.** The study in this article includes 167 students in ten randomly selected sections of an introductory biology laboratory course at a large university in the Southeast. The laboratory course is taught alongside the introductory biology lecture course, and the laboratory courses were chosen for the sample due to its flexibility in lecture. The majority of the sample was Caucasian, about 5% were African American, about 4% were Asian, and about 1% were Hispanic. About 27% of the sample were males, while 73% were females. About 64% of the sample were freshman, 24% sophomores, 8% juniors, and 4% were seniors. A total of 86 students received Treatment Two (static visuals), while 81 received Treatment One (animated visuals).

**Research Design and Methodology**. The study in this article was a regular, original experimental study that used quantitative data to make conclusions. The pretest was designed to provide a baseline and confirm that students in both treatment groups began the course with comparable prior knowledge. The posttest results would provide data that suggests students’ understanding of photosynthesis after the lecture, which could then be compared to determine if any significant difference between the two treatment groups occurred. This study matched student demographic information obtained from the university registrar to student performance on the assessments, while removing student identifier data. The independent variables assessed in this study were the differences in external representations (ER) included in the lecture portion of the laboratory course. Treatment One introduced students to the basic concepts of photosynthesis as part of a lecture presentation using a photosynthesis animation from the VCell Animation Collection. Treatment Two introduced photosynthesis in a lecture presentation using static images developed by the VCell team as a step-wise series of figures to denote the multistep process. The graphics developed for the animated visuals are of the same style and level of detail as those used for the static visuals group, so that difference of graphics cannot affect results. To ensure that no other variables would affect the results of the two different treatments, the same instructor was used for all ten sections, and a team of reviewers evaluated the differences in recorded lectures and rated that they were equivalent regarding concepts taught. Five of the ten sections were randomly selected to receive Treatment One, and the other five received Treatment Two. The same instructor presented the lecture to all ten sections using identical presentation slides except for the ER used. Quantitative data was collected from the results of the pretest and posttest assessments and compared across the two treatment groups to determine a level of significant difference. The research team for this study assessed students’ conceptual understanding using a diagnostic pretest consisting of 10 questions that were focused on basic understanding of a variety of biological concepts, 10 questions used as a test of prior knowledge focused on photosynthesis, and 5 questions covering student background including a five-point Likert scale to gather information on students’ feelings toward learning with multimedia resources. The posttest assessment was a 10-question instrument using isomorphic questions focused on photosynthesis from the pretest, based on questions from the textbook used in the course. The pretest was administered during the first week of the semester. Students then received either Treatment One or Treatment Two during the photosynthesis lecture. The posttest was administered at the end of the lecture on photosynthesis.

**Research Data Analysis.** Descriptive statistics were compiled and inferential analysis run comparing treatment groups using the R statistical programing package. An analysis of students’ learning was provided using a normalized gain score obtained from the results of the pretest and posttest. Cohen’s d was used in the results of this study to illustrate the difference between the means of the two treatment groups. These statistical tests were used to compare the two treatment groups, which can directly answer the research question that addresses the difference in learning outcomes between static and dynamic ER. Analysis of the pretest results showed no significant different in baseline scores between the two treatment groups where p = 0.85. The analysis of posttest results showed significant difference based on the treatment, with p < 0.001. The article includes two figures: (Fig 2) *Normalized Gain Score Comparison for Imagery Types (photosynthesis)* that graphs the differences between the two treatments, and (Table II) *Analysis of variance table for possible extraneous variables* that considers the following preliminary factors: previous enrollment in the course and high school GPA, student standardized test scores, feelings toward multimedia learning, and general demographic information. The comparison between the two treatment groups shows that students who viewed dynamic animation as part of a classroom lecture on photosynthesis have higher normalized gain scores on a concept assessment as compared to those who viewed static images. Students who learned with dynamic animations performed significantly better than those who received Treatment One with only static visuals, indicated by Cohen’s d = 0.52.

**Research Discussion/Conclusions.** The study’s conclusions related to the original purpose in that the results of the posttest indicated that students who received Treatment Two outperformed those who received Treatment One on the posttest. Implications of these findings are that instructional strategies that incorporate dynamic animations offered by VCell promote greater student conceptual knowledge on the topic of photosynthesis. The authors conclude that biology professors can feel more confident using the VCell Animation Collection in their lecture for complex biological processes like photosynthesis in lieu of static images. The statistical results support the conclusion that dynamic animations improve student understanding of photosynthesis. This study was limited to one semester of one course at one university. It also only focused on one particular topic; photosynthesis. Thus, the authors recommend replicating the study with a variety of different topics within the VCell Animation Collection, because the topic of photosynthesis involves the interconnection of smaller factors for understanding the topic as a whole. The authors suggest that for future research, a larger population might be more representative. They recommend that researchers improve the measurement instruments and possibly incorporate item response theory, since the one used in this study was only short multiple-choice questions. They also suggest investigating the comparison between the two treatments on content retention over a period of time.

**References Quality**. The sources cited in this article were pertinent to the study. The authors declare that previous research on the topic of effective instructional strategies that incorporate various ERs is conflicting, while the use of such ERs grows in popularity in undergraduate biology curricula. The authors also refer to previous research that indicates that students struggle to grasp complex content in life sciences due to the interconnected nature of its working parts. The previous successes and failures of instructional uses of static images and dynamic animations were evaluated and analyzed for cognitive data that explains such results, which the authors used to develop this study.

**Overall Assessment**. This study addressed a very specific learning objective with two specific instructional strategies, and the results provide an answer to my research question about the effectiveness of instructional strategies that incorporate 3D animation in undergraduate biology courses. This study focuses on the process of photosynthesis, which is a prime example of the type of complex molecular process I want to investigate. The study also compares the use of static images compared to dynamic animations, which helps to address my research question of when it is more effective to use 3D animations by demonstrating the effectiveness of animations over static images. The results indicate the animations improved student comprehension and retention of the content compared to static graphics, which encourages future use of animations in biology curricula. This article supports the need for my research paper, because it declares that ERs are becoming more common for teaching biology/biochemistry/chemistry processes, and its use can have an effect on students’ understanding of complex content.

### Visualizing Protein Interactions and Dynamics: Evolving a Visual Language for Molecular Animation

**Article Reference.** Jenkinson, J., & McGill, G. (2012). Visualizing Protein Interactions and Dynamics: Evolving a Visual Language for Molecular Animation. *CBE—Life Sciences Education, 11*(1), 103-110. doi:10.1187/cbe.11-08-0071

**Research Query**. This article relates to my research question,

1) In higher education biology and biochemistry curricula, when are instructional strategies that incorporate 3D animations most effective for improving comprehension and retention of complex molecular processes?

**Abstract**. This article addresses previous research in the field of biology education that demonstrates the need for increasingly detailed visual representations due to the common challenges in accurately conveying complex and dynamic processes to undergraduate students. Previous studies pinpointed subject areas that are particular difficult to teach and understand including protein conformational change, diffusion and random molecular motion, and molecular crowding. The authors of this study designed animations that represented these concepts, specifically, stem cell factor ligand and cKit receptor tyrosine kinase. They tested the relative effectiveness of the animations on undergraduate students’ comprehension and retention after they viewed one of the four different versions of the animation each with increasingly complex visual detail. In posttest evaluations, the authors not only measure students’ overall comprehension, but they also review mean scores for basic concept questions and advanced questions, in an effort to make a correlation between students’ level of understanding and the type of animation they viewed. Results from the study conclude that the more complex animations were more effective for students’ overall understanding of these processes and for retention of basic concepts related to the content. This suggests that in select learning contexts, instructional strategies that incorporate 3D animations of high visual complexity may be more desirable for conveying dynamic cell binding events than less complex animated treatments.

**Research Questions/Hypotheses**. The authors of this article conducted a study to examine the effectiveness of 3D animations of protein conformation and molecular motion with varying levels of complexity. They hypothesize that students who view more complex animations will perform better on questions of abstract concepts than those who view less complex animations. They also hypothesize the opposite – that students who view less complex animations will outperform those who view increasingly complex ones on questions of basic concepts.

**Description of Sample.** A total of 131 undergraduate biology students at the University of Toronto, Mississauga made up the sample for the study in this article. Students were recruited to participate and given a $20 gift certificate when the study was completed, so this was not a mandatory part of any specific course. The age of participants ranged from 18-24 years old, with 19 in their freshman year, 52 sophomores, 33 juniors, and 27 seniors. Students were only able to enroll in the study if they completed a first-year introductory cell biology course because the content used in this study requires some prior knowledge in that area.

**Research Design and Methodology**. This was an original, regular study that collected quantitative measurements to support or refute the hypotheses. Four versions of the same animation of stem cell factor ligand and cKit receptor tyrosine kinase were developed at the Center for Molecular and Cellular Dynamics at Harvard Medical School in collaboration with Digizyme, whose CEO is one of the authors of this article. Each of the four treatments included additional visual complexity, while the timing and framing of the animation remained consistent. Narration and audio were also excluded from all treatments, so that visuals were the only variable affecting learning outcomes. Throughout the study, students take a pretest, an immediate posttest, and a delayed posttest, all of which include 10-short answer questions for which the correct answer cannot be guessed. The authors previously piloted these questions on four students and modified based on their feedback before implementation in the study. Each of the questions was one of two types: those that measure surface-level understanding of basic concepts, and those that measured deep understanding of complex concepts. The questions were different on the pretest, posttest, and delayed posttest, but an attempt was made to make them isomorphic, so that the mean scores at the three time intervals would not be affected by difficulty level of the questions. The pretest was used to establish a baseline measurement to ensure that students across the four groups had an equivalent level of prior knowledge. The variations in treatment are the independent variables, while the dependent variables are students’ scores and responses to the two posttests: one administered immediately after viewing the animation, and one two weeks later. Students worked individually in a computer lab and were randomly assigned a number 1-4 for which they received an instructional packet corresponding to one of the four animation treatments. Before viewing the animation, all students took the same pretest and were given no feedback. Then, they were instructed to view the animation as many times as they wanted before taking the posttest. All students took the same posttest as soon as they were finished viewing the animation. Two weeks after the initial posttest, students took the same delayed posttest online through BlackBoard. The students’ responses from all three assessments were graded as either correct for 1 point, or incorrect for 0 points. The mean scores for each of the four groups was compared at posttest and delayed posttest to identify any significant difference in initial comprehension and memory retention between treatments. The mean scores for basic concept questions were collected and compared across the four groups, as were those for the advanced concept questions. The authors were careful in their design of the materials so that four versions of the same animation only differed in visual complexity, while other factors like timing and framing remained constant. They also designed the pretest and posttests strategically, incorporating short-answer questions to discourage students from guessing, and including specific questions that measure either a surface-level or a deeper understanding of the content. Both of these careful decisions mean that the results will be narrow and focused to the hypothesis of the study.

**Research Data Analysis.** The data collected in this study were quantitative, utilizing several statistical tests. The authors analyzed the data using ANOVA, Levene’s test for homogeneity of variance, and Mauchly’s test for compound symmetry of the variance-covariance matrix. These statistical tests allowed the researchers to compare multiple variables (the four treatments) at three time intervals, and compare mean scores from each group for each of the two question types. The data gathered from this analysis provides direct answers to the author’s research questions. Test scores were found to vary significantly between the three assessment points, with p < 0.001. The mean scores of each of the assessments for the 4 treatment groups was compared as well. As expected, there were no significant differences across groups for the pretest, however there were significant differences in mean scores between the four treatment groups for posttest (p = 0.002) and delayed posttest (p = 0.008). This article includes several appropriate figures and tables that visually display results of the data analysis. The author found that students’ overall performance on the posttest and delayed posttest was significantly greater with increasingly complex animations. This part of the findings supports the author’s question of the overall effect of different visual treatments on students’ comprehension and retention of molecular processes, in that the more complex versions had a positive influence on learning outcomes.

Data showed that there was no significant difference between the groups in correctly answering basic concept questions, which does not support the author’s hypothesis that students who view simpler animations will outperform those who view more complex ones on posttest questions regarding basic concepts. Conversely, data supported the other hypothesis that increasingly complex animations would foster greater understanding of abstract concepts, with students in the two more complex animation groups scoring significantly higher on abstract questions than the other two groups.

**Research Discussion/Conclusions.**  In this article, the authors maintain focus on the original purpose of the study very well, drawing conclusions that address each of the 3 research questions with statistical results. The main goal of the study was to identify the impact of visual complexity on students’ comprehension and retention of dynamic molecular processes. Statistical results showed higher scores on both of the posttests for the two groups that viewed more complex animations than the other two groups, so the conclusion was that increasing visual complexity fosters a greater understanding of these processes. The authors concluded that the hypothesis that less complex animations would foster a greater understanding for basic concepts was not supported due to the results of the posttest, because students’ ability to answer basic questions did not significantly differ based on the type of animation they viewed. There was, however, a significant difference in the results of the delayed posttest, as students in the two more complex animation groups scored higher on basic questions than those in group one who viewed the simplest animation. The second hypothesis of the study was that increasingly complex animations would foster a greater understanding of the more advanced concepts related to molecular events than simpler animations, and the authors concluded this to be true due to the data from a comparison of scores on advanced questions from the initial posttest. Scores on advanced questions from the delayed posttest across all four treatment groups were comparable, though. The overall conclusion from these results is that the two more complex animations did have lasting learning effects, but only for basic concepts of the molecular process.

This study focused only on visual variables, so audio and narration in either audio or text form was purposefully excluded from all of the animation treatments. This choice detracted students from overall enjoyment of the exercise and from the potential educational benefits. Knowing that principles of multimedia suggest that a combination of visuals, text, and narration will be most effective, the authors propose that future research in this area should utilize these principles to create more effective animations and study the various effects of more than just visual complexity. The authors also discuss a limitation created by the slight difference in short-answer questions on the three assessments, despite the attempt to isomorphically match the questions. They suggest that the lack of a control group in this study limits the clarity of the true effect of question variation. A third limitation of the study is that the mechanism that explains why students in groups 3 and 4 outperformed those in group 1 in complex questions is not able to be identified. The authors consider that the more complex animations may not have fostered a deeper understanding but might simply have provided students with more information than those in group 1. The authors suggest that a more in-depth analysis of the student responses on the assessments could provide deeper insight as to how well students understood the concept due to the complexity of the animation. The author discusses a few implications of this study for the instructional design, education, and life sciences fields. Because this study focused on various levels of visual complexity and how those affect students’ understanding of molecular environments, the results of the study can be applied to other complex processes taught in life sciences courses, especially those with several details and moving parts. He mentions that recent advances in cell and molecular biology add to the level of detail involved in full understanding the big picture, so more sophisticated visual representations are becoming crucial for conveying all of the pertinent information. He hopes that this study draws attention to the potential effects that varying visual complexity can have on students’ ability to understand complex dynamic processes in biological sciences.

**References Quality**. I believe that the sources cited in this article were useful to the study because they demonstrate the challenges that undergraduate biology professors and students face regarding complex and dynamic molecular processes. The authors mention a few studies where biology educators examined the most common challenges for conveying molecular concepts to students in a way that avoids rote memorization but fosters a deeper understanding of the big picture. The conclusions from these studies report that students have a difficult time with biological processes involving interconnected molecular reactions, particularly protein conformational change and stability, diffusion and random molecular motion, and molecular crowding. These three concepts became the basis of selection of content used in this study of varying visual complexity.

**Overall Assessment**. I believe this article provides useful insight on the precise effect that highly detailed 3D animations have on undergraduate students’ comprehension and retention of complex molecular processes. One of my research questions involves the evaluation of instructional strategies that include 3D animations for teaching complex molecular processes and when they are more effective for comprehension and retention than other instructional strategies. In this study, the authors compare the effectiveness of more visually complex animations over less detailed ones, concluding that advanced concepts are more easily comprehended and basic concepts are more easily retained when students view animations with more visual complexity. So, this conclusion provides two specific answers to my question. First, when students are required to remember basic knowledge of molecular processes over a period of time, highly detailed animations will be more effective than less detailed animations. Second, when students are required to comprehend complex concepts regarding protein conformational change and stability, diffusion and molecular motion, or molecular crowding more visually complex animations will be more effective than less visually complex ones.

While this article contains valuable insight into the effectiveness of animations for learning molecular processes among undergraduate students, the narrow scope of the study can only lend a portion of useful data to my research. This study only compares different versions of animations, whereas my research question is broad and includes the comparison of instructional strategies that use 3D animations to any other type of instructional strategy.

### The Value of Animations in Biology Teaching: A Study of Long-Term Memory Retention

**Article Reference.** Oday, D. H. (2007). The Value of Animations in Biology Teaching: A Study of Long-Term Memory Retention. *CBE—Life Sciences Education, 6(*3), 217-223. doi:10.1187/cbe.07-01-0002

**Research Query**. This article relates to my research question,

1) In higher education biology and biochemistry curricula, when are instructional strategies that incorporate 3D animations most effective for improving comprehension and retention of complex molecular processes?

**Abstract**. The author of this article has completed previous work that indicates that narrated animation is more effective at communicating a complex biological process (signal transduction) than an equivalent static graphic with a figure legend. He states that there is a lack of research on the effect of animated visuals for long-term retention of biological content, and the results of a study that examines this may offer valuable information about teaching and learning. This study examines students’ long-term retention of content after viewing one of three varying animations or two graphics. The results of the study show that students who viewed an animation retain more information after 21 days than those who only viewed static graphics. The article also includes comments from students after viewing one of the visuals to provide additional insight into the value of animations.

**Research Questions/Hypotheses**. The author states that the primary goal of this study was to determine whether short- and long-term memory retention are greater with an animation compared with a graphic regardless of the availability of a narrative. Because narration is not always included in freely available online animations, this study only included animations that did not have narration or audio of any kind. These animations were compared to graphics that did and did not include a legend, so that the difference in short- and long-term retention for static graphics with or without a legend could be evaluated as well.

**Description of Sample.**  The sample for this study includes 393 undergraduate student responses in five different tutorial groups in two different junior level courses at the University of Toronto at Mississauga (Human Development, and Advanced Cell Biology). The author does not explicitly state what is meant by “tutorial groups,” so it is not clear if this is possibly a subset of students in the courses who were receiving extra tutoring, or if this includes all students enrolled in these courses. The supplemental materials provided with the article (the questionnaires) do suggest that these were the supplementary lecture blocks (recitations) that all students in the course had to attend. The 393 responses refers to initial evaluations completed by 213 students and retention questionnaires completed by 180 students, where the decrease is due to students dropping the course. The reason for selecting these groups is not explicitly stated in the article either, however, it is noted that both of these courses were taught by the author, so one can assume that convenience played a role in the selection process. No demographic data about the students is included in this article likely because the questionnaires were completed anonymously.

**Research Design and Methodology**. This study, led by O’Day, was a follow-up study to his previous work in 2006, Animated Cell Biology: A Quick & Easy Method for Making Effective High-Quality Teaching Animations, where he found that students who viewed an animation of the dual signaling pathway performed better than those who viewed a static graphic. The study produced both quantitative and qualitative data, and though not explicitly stated, could function as a pilot study for future researchers evaluating long-term memory retention since this was one of the first to do so for biological animations. This study includes a static graphic and animation version for both the apoptosis and cholesterol content groups, but only includes an animation version for those learning about the influenza virus. Since the goal of the study was to determine whether short- and long-term retention of content is greater among students who view an animation compared to a static graphic, I do not see how the inclusion of the influenza virus group is relevant without a static graphic group with which to compare it. Additionally, the retention version of the questionnaire only contains Part II, while the initial version also includes Part III which offers valuable insight into students’ experiences and opinions. I believe that a similar addition to the retention questionnaire that allows students the opportunity to provide any written comments about how much they thought the visual helped them to remember the content would provide useful qualitative data to support the quantitative results. The independent variables for this study are the different versions of visuals presented to students, while the dependent variables are the students’ scores and responses on the initial evaluation and retention questionnaire. Students were part of one of five tutorial groups:

* Human Development course, learning about apoptosis, viewed an animation
* Human Development course, learning about apoptosis, viewed a graphic without a legend
* Advanced Cell Biology course, learning about cholesterol uptake, viewed an animation
* Advanced Cell Biology course, learning about cholesterol uptake, viewed a graphic with a legend
* Advanced Cell Biology course, learning about influenza infection, viewed an animation

Students in five different tutorial sections for the two junior level biology courses learned about apoptosis, cholesterol uptake, or influenza virus in lecture and then viewed either an animation or static graphic individually on a computer during the weekly tutorial section which was guided by a TA. The quality and level of detail in the animations was preserved in the graphics, so that no variation in visual information provided could affect the results. Immediately after viewing the visual for a specified amount of time, students took no more than 30 minutes to complete an anonymous initial evaluation on paper, and the links to the visuals were shut down so that students could not access them again. After 21 days, students remaining in the course completed an anonymous retention questionnaire. Specific instructions were provided to the TAs for the tutorial groups, so that instruction for each group was consistent. An answer key was provided for grading of the specific questions in Part II of the questionnaires. The initial evaluation includes three parts; Part I Introduction (questions that pertain to the type of visual viewed and number of times viewed given a specified amount of time), Part II Specific Questions (content specific questions that evaluate comprehension and retention of the material), and Part III We want your Opinion (asks whether the student found the material useful, and if not, an explanation as to why, and a section for optional comments). The retention questionnaire that was administered 21 days after viewing the visuals contained only Part II, with the same questions as the initial evaluation. Part II varied depending on the content (cholesterol uptake, apoptosis, or influenza). The specific questions from Part II were graded for each student response, and the mean and SE of the mean were calculated for each group. Seventeen of the initial questionnaires were excluded from the results due to incorrectly completing Part I.

**Research Data Analysis.** The data collected from the two questionnaires was both qualitative and quantitative, because grades from Part II provided mean scores, while the responses in Part III offered opinions and comments from the students. The data were analyzed not by student, but by tutorial group and the mean scores and standard error of the mean were calculated for each group at each stage of assessment. The article includes two figures with results data with appropriate numbering and titles, but the most informative one, in my opinion, is Figure 2 which contains a color-coded bar graph depicting the mean +/- SEM scores from Part II of the five initial questionnaires and five retention questionnaires. I like this graph because I can make several visual comparisons: graphic with legend (cholesterol) vs graphic without a legend (apoptosis), apoptosis graphic compared to apoptosis animation initially and after retention period, and the magnitude of difference between initial cholesterol scores compared to retention scores. The other figure included in the article, Figure 3, depicts an analysis of correct responses on the 10 questions for the apoptosis and cholesterol uptake groups. This study uses appropriate statistical data to address the research question in the apoptosis and cholesterol uptake groups, but as previously mentioned, does not do so for the influenza virus group. The author appropriately discarded questionnaires that were not correctly completed. The use of mean and SEM was consistent for all groups both initially and after 21 days. The analysis of percentage of correct answers was appropriate for evaluating performance on individual questions for the apoptosis and cholesterol questionnaires. All of the mean scores from the groups initially and after 21 days were significantly different from each other (p<0.05), except for that of the cholesterol uptake animation group.

The results and analysis of the data in this study supported the hypothesis that animations lead to greater long-term memory retention than simple graphics. For two complex biological processes, apoptosis and cholesterol uptake, students who viewed the animation scored higher on the retention questionnaire than those who viewed the graphic in both cases. The author discusses the well-established “forgetting curve” that suggests the logarithmic decline of memory retention over time, and that in educational terms, most students remember ~21% of information after 2-4 weeks. While students who viewed the graphic remembered much more than 21% of the content (likely due to the nonrandom nature and relevance of the content), students who viewed the animation remembered 79-83% more than those who viewed the graphic, indicating that animations lead to greater long-term retention.

The evaluation of correct responses per question did not directly correlate to the author’s hypothesis; it was to determine if the results from Stith’s 2004 study could be replicated. He found that the viewing of animations did not help students to better answer definition questions, but animations did help students with questions involving dynamic processes. The results from O’Day’s study partly supported these findings for the cholesterol uptake groups, but overall did not support Stith’s data. With this conclusion, the results of this study then suggest that animations lead to increased long-term memory retention regardless of the nature of the material.

**Research Discussion/Conclusions.** The conclusions of the study were related to the original purpose of the article in that animations improved long-term memory retention of biological processes. The implications of this study were briefly discussed; its most important contribution to the field was that it was one of the first studies to demonstrate the long-term effectiveness of animations compared to static graphics in life science instruction. The author questions further why are animations more effective for long-term memory retention, and when are animations more effective than static graphics? The statistical results of the study support the conclusion that animations of complex biological processes provide greater long-term memory retention than static graphics of such processes. Students in both the apoptosis and cholesterol groups received higher scores on the retention questionnaire after viewing animations compared to those who viewed static graphics, even when initial scores did not illustrate a benefit from animation. This study was performed in only two courses at one institution taught by the same professor, so more representative results would be found from a larger sample population. The study also focused on only two biological processes, whereas a comparison with several types of content both biological and outside of the sciences may be useful for determining whether animations are better for long-term retention. The results of this study compared to Stith’s study mentioned previously prompted the author to suggest that for future research, a more strategic design of questionnaires could provide more valuable insight as to when it is more effective to use animations instead of static graphics. The author also recognizes his use of only animations without narration or audio in the study, and recommends testing both types of animations against graphics with and without a legend in order to collect more insightful data about the various types of visuals.

**References Quality**. The author refers to multiple studies where students who viewed a 3D animation after a lecture on a complex biological process scored significantly higher on a posttest than those who had not viewed the animation. He mentions these studies because they evaluate only the immediate comprehension and retention of the content, stating that there is a lack of data for the effects of animated visuals on long-term retention. He also cites literature that suggests that animations with narration are more effective than animations without narration, but narration is not always available with online animations, and this determined the basis of this study where animations without narration were evaluated against static graphics.

**Overall Assessment**. In Supplemental Material 1, part of the script for the TA’s introduction to the class says, “As discussed in lecture,” which caught my attention and became a concern (O’Day, 2007). If this refers to a brief lecture conducted by the TA immediately before the study exercise, then this may have an effect on students’ prior knowledge and thus level of comprehension reflected in the initial evaluation. If this mention of lecture were referring to a lecture given by the professor on a day before the tutorial section was held, this allows for more opportunity for students to have already been studying and learning the content ahead of time, which could greatly affect prior knowledge before the study exercise, thus affecting the scores on the initial evaluation. In either case, the variable of prior knowledge should be considered in the study, so I believe a pretest should have been administered before the students viewed one of the visuals, to ensure that the results of the initial evaluation are representative of the type of visual viewed.

The study in this article directly investigated my problem statement regarding the effectiveness of instructional strategies that incorporate 3D animations for enhancing student comprehension and retention of complex molecular processes. This article addresses the comprehension portion of my research, specifically long-term retention, which is an important aspect of instructional design. The results show that animations improved long-term memory retention, but did not illustrate how or why they are more effective than static graphics. Additional research needs to be conducted to further analyze these effects.

### Bio-Organic Reaction Animations (BioORA) Student Performance, Student Perceptions, and Instructor Feedback

**Article Reference.** Gunersel, A. B., & Fleming, S. (2014). Bio-organic reaction animations (BioORA): Student performance, student perceptions, and instructor feedback. Biochemistry and Molecular Biology Education, 42(3), 190-202. doi:10.1002/bmb.20773

**Research Query**. This article relates to my research questions,

1) How do these instructional strategies with 3D animations affect students’ motivation with learning complex molecular processes?

2) In higher education biology and biochemistry curricula, when are instructional strategies that incorporate 3D animations most effective for improving comprehension and retention of complex molecular processes?

**Abstract**. The purpose of this study was to assess new a visualization program produced by BioORA using 3D animation software of molecular events. Previous research states that simulations and animations can be useful tools for teaching abstract molecular processes in biochemistry and chemistry that are not able to be directly observed, especially processes that involve moving parts. The authors also cite studies that establish the relevance of student perception when evaluating instructional tools, particularly their interest in the content, their value of the topic, and their perceived ability of understanding the material. This previous literature provided the foundation for the research questions in this study, so that the authors and creators of BioORA could assess the impact and benefits of their animation software on undergraduate students. The results of this study showed that BioORA influenced students’ performance on content-related quizzes across four different classes learning about enzyme kinetics. Qualitative analysis overall supported the quantitative data, in that the BioORA lessons had an impact on student interest, value, and ability with the content.

**Research Questions/Hypotheses**. The authors of this article had several research questions for their study (Gunersel and Fleming, 2020):

(1) How do students perform on basic biochemistry questions related to enzymes after a lesson with regular teaching methods (e.g., mostly lecture with PowerPoint presentations, diagrams, drawings) and after a lesson with BioORA?

(2) What are students’ perceptions of and experiences with BioORA, and how do they compare to those regarding regular teaching methods?

(3) What are the faculty’s experiences with BioORA?

(4) Are there differences between student interest and value regarding the topic and student perceptions of ability after a lesson with regular teaching methods compared to a lesson with BioORA?

**Description of Sample.**  The sample for this study contained undergraduate students in four separate biochemistry courses learning about various enzymes. The demographics of each class is explicitly specified on page 193 of the article, but students in all four classes were age 20-38. This study also includes interviews with the instructors for each class, three of which were Caucasian males in their 30s, and one female instructor was Caucasian in her 40s. Class 1 contained 45 students, Class 2 had 19 students, Class 3 had 25 students, and Class 4 contained 44 students. These classes were chosen for the study because they each include multiple lessons on enzymes, and these are the types of animations that BioORA had produced.

**Research Design and Methodology**. This study was an original, regular experimental study that produced both quantitative and qualitative results. This study included four classes that were analyzed individually. The instructors for each course taught a lesson on one enzyme in their course the way they normally did. Then each instructor taught another lesson on a different enzyme using BioORA animations during their lecture. The instructor for Class 1 first taught aminotransferase and then taught chymotrypsin using BioORA. The instructor for Class 2 first taught chymotrypsin and then taught malate dehydrogenase using BioORA. The instructor for Class 3 first taught isocitrate dehydrogenase and then taught malate dehydrogenase using BioORA. The instructor for Class 4 first taught xanthine oxidase and then taught pyruvate carboxlyase using BioORA. Immediately following each lesson, the instructors distributed a quiz that tests students’ knowledge of the content. The researchers gave the instructors five questions and were told to choose at least three of them to include in their quizzes. These were basic enzyme questions that could apply to each of the enzymes appropriately. After the quiz, students completed a survey containing Likert-scale questions and open-ended questions that were identical across classes and varied only between the “regular” lessons and BioORA lessons. These survey questions pertain to students’ learning experiences, their value of the topic, and their own perception of comprehension. After both lessons were completed, the researchers interviewed each instructor for 30-50 minutes where they discussed how the instructors used BioORA in their lessons, how they felt it helped them with the lesson, and to what degree they felt the BioORA animations helped students learn the material. These interviews were taped and transcribed for records.

The methods of this study were well-designed to match the researchers’ hypotheses. The content-specific questions on the quizzes produced data to compare students’ performance after a regular lesson compared to a lesson with BioORA. The student responses from the surveys provided insight into their perceptions of the two lessons comparatively, and addresses the authors’ interest in the difference between learner engagement and students’ perception of their ability. The comparative analysis between the interviews with instructors provided insight into their experiences with BioORA. The independent variables for this study are the two lesson styles in each of the classes, while the dependent variables include all of the responses to the quizzes, surveys, and interviews. The researchers collected data for this study using identifiers on all materials so individual student performances could be compared with and without the BioORA lesson.

**Research Data Analysis.**  The authors used dependent t-tests to compare performance on the quizzes and Likert-scale responses on the surveys across the four classes. The authors also used constant comparative method for their qualitative analysis on the open-ended questions on the surveys and on the interviews with the instructors. Both of these methods were appropriate for the research questions, because they provided statistical analyses of students and instructors experiences and perceptions of using BioORA. In their quantitative analysis, the researchers stated a level of statistical significance when comparing quiz scores and survey responses from the regular lessons compared to the BioORA lessons, which allowed them to draw conclusions about the impact of their animations. The qualitative analysis of open-ended responses and instructor surveys became quantitative when the researchers totaled the number of responses within each category and compared their frequency using bar graphs. This type of analysis was very useful for drawing conclusions based on open-ended feedback. In their discussion, the authors compared the quantitative results individually for each class, first determining if the quantitative data showed higher ratings for the BioORA lesson overall. Then, they determined if the qualitative data from the open-ended responses after the BioORA lesson supported the quantitative data for that class. The authors include several charts and figures in their appendices, all of which are very useful for interpreting key data that illustrates their conclusions.

The authors found that students in three of the four classes performed better on their quiz after the BioORA lesson than after the regular lesson at a statistically significant level. With this analysis, they concluded that the BioORA lesson had a positive impact on student learning. For their second and fourth research questions regarding the students’ perceptions and experiences with BioORA, the authors found that ratings on survey questions relating to interest, attainment value, and perceived ability were statistically higher in two classes after the BioORA lesson. These questions were generally higher in the third class, and one question in particular was statistically calculated to be significantly higher after the BioORA lesson in the fourth class. The authors conclude that BioORA may have positively impacted students’ engagement with the material, the value they place on the topic, and their perceived understanding of the content.

**Research Discussion/Conclusions.** The conclusions of the study were related to the original purpose of the research in that the authors successfully evaluated their BioORA animation software using several forms of criteria. The authors conclude that students performed better with BioORA lessons than regular lessons, that students responded positively overall to the animations, and that faculty found BioORA useful for teaching and learning the content. The conclusions of this study, supported by statistical results and previous research in the science education field, implied that professors of chemistry and biochemistry courses can confidently use BioORA animations in their lecture to teach complex molecular processes. With their feedback portion of student and instructor evaluations, the authors were able to categorize and identify what the majority of the sample experienced and perceived after the BioORA lesson compared to the regular lesson, as well as collect valuable suggestions to improve the software. The authors mention that students suggested that the animation be used as a supplemental tool for lecture instead of acting as the only source of information. Other feedback included changes to the software itself, like voiceover pace and labeling, while some instructors recommended including a preparatory session or guide to familiarize students with the use of the software.



**References Quality**. The authors provided a thorough background of studies that evaluated computer simulations and animations for teaching abstract concepts like those in chemistry and biochemistry courses. They cited about 11 sources that support the positive effect of animations for teaching complex molecular processes, so that they can validate the need for and potential learning benefits of their animation software. A portion of this study involved students’ perceptions of the animations, and this is due to previous research on assessing teaching tools that. The authors cited a few sources that emphasize the importance of student perceptions and interest when evaluating instructional media, and this became a critical component of their research questions. In their discussion, the authors cited various sources to support an explanation for the most frequent pieces of feedback from the students and instructors. These included studies and principles regarding the effect of text and narration in animations and each student’s learning preference, which demonstrates credibility and the authors’ knowledge of the topic.

**Overall Assessment**. The authors of this article were very thorough in their write up and study design, so I think this is a fairly credible addition to my research paper. Additionally, I believe the conclusions from this study provided valuable pieces of information that partially answer my research questions. While this study proved that BioORA had benefits for several different lessons on enzymes over traditional lecture, it did not address whether using these animations for molecular processes is the “most effective” time for doing so. This article only demonstrated the success of instructional strategies that use 3D animations in one type of scenario and did not compare it to others. Regarding my other research question about the effect of 3D animations on student motivation, the survey and interview responses provided valuable insight about the difference in interest and value of the topic that students have after viewing the BioORA lesson compared to the regular lesson. Individual student comments also illustrated the types of responses that undergraduate students had after the BioORA lesson, suggesting that 3D animations can affect student motivation in a positive way.

### Metabolism in Motion: Engaging Biochemistry Students with Animation

**Article Reference.** Long, S., Andreopoulos, S., Patterson, S., Jenkinson, J., & Ng, D. P. (2021). Metabolism in Motion: Engaging Biochemistry Students with Animation. *Journal of Chemical Education, 98*(5), 1795-1800. doi:10.1021/acs.jchemed.0c01498

**Research Query**. This article relates to my research questions,

1) How do these instructional strategies with 3D animations affect students’ motivation with learning complex molecular processes?

**Abstract**. This article begins with an evaluation of current literature in biology higher education on the challenges students face when learning complex molecular processes. These studies indicate that traditional instructional approaches cause students to struggle to develop a high-level understanding of the metabolic system, and that biology education should shift toward an alternative curriculum that focuses on connecting concepts for a big-picture understanding. This level of understanding is more useful in real-world applications regarding higher level education and research in biochemistry. The authors of this article developed an animation with the intention of encouraging high-level comprehension of metabolism among second-year undergraduate students and collected feedback from an online survey that reported how the students felt about the value of the animation after viewing it.

**Research Questions/Hypotheses**. Students have difficulty developing a high-level understanding of complex and dynamic molecular processes such as metabolism, so the authors of this article set out to solve this problem by developing a big-picture animation of the metabolic system. The authors had three goals they wanted learners to achieve by viewing the animation: (i) identify the main biological energy sources, the metabolic pathways, and the intermediate metabolites connecting these pathways; (ii) recognize that metabolism is dynamic and adapts based on varying energy demands; and (iii) apply metabolic knowledge to “real-life” scenarios while making connections between different visual depictions of metabolism. Additionally, I believe the researchers also evaluated the perceived effectiveness of using 3D animations to convey high-level concepts of metabolism among students.

**Description of Sample.** This study was completed with second-year undergraduate students at the University of Toronto. The sample contained life science students in three offerings of an Introductory Biochemistry course, and four offerings of the School of Continuing Studies online course, Biochemistry with a Medical Perspective. While the animation was available for all students in these courses, only 105 completed question 1 on the elective survey, and 35 students of those completed questions 2 and 3.

**Research Design and Methodology**. The study in this article provides both quantitative and qualitative data, but the focus is on the latter. This was an original study completed by a team of graduate students who built upon previous undergraduate course enrichment projects to develop the animation. The researchers carefully designed the animation to specifically address all three learning goals for the study, however their survey did not measure students’ success in achieving those goals. There were no defined variables in this study, because the collection of data was mainly qualitative, and the researchers did not take any benchmark measurements.

The students from the two biochemistry courses first completed their respective module on metabolism, and were then granted access to the 3D animation to view as many times as they like. Students opted to provide feedback on an anonymous Microsoft Forms survey. Responses to the surveys were collected anonymously online via Microsoft Forms. Researchers totaled the number of students who selected each of the five responses for question 1, and the number of students who responded ‘yes’ and ‘no’ in questions 2 and 3. The survey was optional for students to complete after watching the 3D animation, so the number of participants in the study contained a small percentage of the initial sample of students learning about metabolism. The first survey question asked to what degree they felt the 3D animation facilitated their understanding of glucose metabolism, for which participants selected one of five responses:

* Strongly agree
* Agree
* Neutral
* Disagree
* Strongly disagree

Questions 2 and 3 on the survey were ‘yes’ or ‘no’ format, for which 70 students chose not to answer. Question 2 asked students to rate whether or not they felt better prepared to be assessed on metabolism after watching the animation. The third question asked whether or not the animation influenced students’ approach to learning the material. Following the multiple-choice questions, there was an opportunity for students to provide written feedback on the animation in two sections: “Any other comments?” and suggestions on how to improve the animation (Long et al., 2021, p. 1799). The authors did not state how the online survey was sent to the students, nor did they explicitly state that the survey was optional. The introductory biochemistry course contains ~1500 students per year, for which there were three offerings included in the study, as well as four offerings of the SCS course that contains ~100 students/year (p. 1797). Of these, only 105 students answered question 1, while only 35 answered questions 2 and 3.

**Research Data Analysis.** The researchers analyzed quantitative data by calculating percentages of responses for each survey question. The student comments from the open-ended portion of the survey were compiled by topic and included in this report to support the overall influence of the animation. The authors did not analyze their data using statistical tests nor did they calculate a level of significance of the data. The tables and figures that the authors include in the article are appropriate for the study. 86% of students who completed question 1 of the survey agree or strongly agree “that the 3D animation facilitated their understanding of glucose metabolism,” while 8% responded “neutral,” and 6% strongly disagreed (Long et al., 2021, p. 1798). Of 35 responses, 80% felt more prepared for assessment on metabolism, while 71% felt their approach to learning the content was influenced by the animation. These quantitative data support the hypothesis that this animation fosters a greater understanding of higher-level concepts, such as glucose metabolism. Responses to the open-ended feedback portion of the survey indicated that students found two features of the animation most helpful: the first pertained to the metaphor that encouraged big-picture connections, and the other was the benefit from real-life applications of metabolism. The authors concluded that the popularity of these responses suggests that students succeeded in achieving the selected learning goals for the study.

**Research Discussion/Conclusions.** Qualitative data containing written responses were categorized as pertaining to increased confidence, engagement, and relevance after viewing the animation, and the authors concluded that this indicates that the animations fostered a greater understanding of metabolism at a higher level. The authors suggest that animations like the one they used in the study can provide a high level of understanding required for learning about complex molecular processes that involve connected and dynamic parts. This offers a solution for educators who struggle to convey such processes to their students in a manner that is representative of the bigger idea. The percentages of responses on question 2 on the survey indicated that the majority of students felt more confident in their understanding of metabolism after viewing the animation. That of question 3 also indicated that the majority of students felt the animation influenced their approach to learning the material. With this data, the authors conclude that the animation facilitated learner engagement and increased perceived comprehension of the relationship and regulation between metabolic pathways. The authors do not address the limitations of this study in this article, but I can identify a few based on my review. The study does not include any baseline measures, nor measures of cognitive ability before and after viewing the animation. The data is all qualitative and from a small sample of students. The authors included a section on the survey that asked students for suggestions on how to improve the animation, and a recurring response was that they would have benefited from the animation more if there were detailed information on the on the reactions and pathways. The authors suggest that if educators intend to use this animation in their lecture, that they should supplement it with other materials that provide such detail of the chemical reactions, viewing the animation before and/or after that.

**References Quality**. The authors of this article cite research in the field of biology education that argued for alternative curriculums that steer away from rote memorization and instead focus on the big-picture understanding of connected concepts, their interdependent regulation and implication for real life applications. Other studies mentioned in the article discussed active learning approaches for teaching molecular processes like metabolism, and suggested that these alternative approaches may elicit a higher order of thinking among students. The reason for this argument is that in order for students to truly grasp the concepts of complex and dynamic molecular processes they must have an overall understanding of how the smaller parts interact and connect, and the memorization of molecular interactions is not as pertinent to the overall concept. These statements support the need for the research conducted in this article.

**Overall Assessment**. I believe this article provided a different perspective than the other articles I have chosen to review, as it relies mostly on qualitative data based on the personal feelings of participants. I chose to include this article because it addresses my research question about how instructional strategies that incorporate 3D animations effect student engagement with material on complex molecular processes. Student feedback from the survey in this study particularly addressed the fact that students felt that the animation increased their engagement with the material. This piece of evidence would be more useful to my research if there were quantitative data to support the claim. While qualitative data can often be insightful, I wish that the survey in this study were more carefully designed so as to include questions that measure students’ actual engagement with the material rather than their self-perceived engagement.

### Decorative animations impair recall and are a source of extraneous cognitive load

**Article Reference.** Pink, A., & Newton, P. M. (2020). Decorative animations impair recall and are a source of extraneous cognitive load. Advances in Physiology Education, 44(3), 376-382. doi:10.1152/advan.00102.2019

**Research Query**. This article relates to my research question,

1) In higher education biology and biochemistry curricula, when are instructional strategies that incorporate 3D animations most effective for improving comprehension and retention of complex molecular processes?

**Abstract**. The authors began with an extensive evaluation of previous studies and current literature on cognitive learning, multimedia principles, and the use of animations in higher education. Most importantly noted was cognitive load theory and its function as a lens for understanding how different visuals might be processed cognitively. The authors focus on the seductive details effect, which indicates that the inclusion of interesting but not relevant details impairs learning. They state that while this effect has been studied extensively, most of the research has been on text and still illustrations, leaving a gap for their research on seductive details in animations. The authors attempt to use cognitive load theory to explain the results of previous research and this study, in which extraneous details impair learning. In this study, the authors test the effects of decorative animations against static graphics in a PowerPoint presentation on students’ ability to recall science, technology, engineering, and mathematics content in their respective courses. Results comparing these two types of visuals show that students performed better when asked to recall content for which they saw a static graphic, versus recalling decoratively animated content.

**Research Questions/Hypotheses**. The authors of this study had three hypotheses:

* Decorative animations will impair recall compared with still images
* Animations occupy more working memory resource than still images
* Decorative animations are a source of extraneous cognitive load

**Description of Sample.**  The sample of this study included freshman undergraduate STEM students at Swansea University. While the material was presented to several students, participation in the study was voluntary, and Experiment 1 of this article contained 96 students. The authors do not state which particular courses were included in the study nor why they were chosen. The authors did not also state any sort of inclusion or exclusion criteria in this article.

**Research Design and Methodology**. The researchers first completed a pilot study where they developed and finalized the experimental protocol for this study. This was an original study that used quantitative data to evaluate the results of the study. The independent variables for this study were the different versions of visuals; animated and static graphics. The dependent variables are students’ scores on the multiple-choice and rating questions. This study contained two experiments, for which students were divided into two groups. Experiment 1 contained two parts; in Section A, students viewed a PowerPoint (on either enzyme kinetics or physiology) that played automatically, showing 8 content slides (half with decorative animations and half with still images) that students would see for 30 seconds each. Each content slide was followed by a blank slide and then a multiple-choice question (MCQ) with either a decorative animation or static graphic. Students had 20 seconds to answer each question on their participant sheet, which was turned in before the class started. Whether there was an animation or image on the MCQ slide depending on which of the two groups students were divided into. Section B of this experiment asked students to recall either 10 still images or 10 animated GIFs (depending on their group) and then rate how much mental effort they felt it was. Experiment 2 contained 416 students and acted as a control group. Students only viewed section A from Experiment 1 but with different content.

The researchers collected the student responses from the optional anonymous participant sheets and graded their responses to the MC questions with either 1 point for the correct response and 0 for incorrect responses, so each participant sheet was scored out of 8 points. They also collected the number of correctly recalled images from section B of the experiment, and found the mean for the animated visuals group and static visuals group. They then compared the means from the two groups to determine if there was a significant difference in the scores. The researchers used multiple-choice questions embedded into their PowerPoint presentation that tested students’ retention of the content presented on the previous slide. Students recorded their responses on preprinted participant sheets. Section B of the experiment required students to view a slide containing either 10 still images or 10 GIFs for a specific amount of time and then immediately try to recall as many of them as they can. Researchers graded the number of correct responses and scored each participant out of 10 points. These scores are intended to reflect students’ varying ability to recall content after viewing different versions of images.

**Research Data Analysis.**  The researchers used statistical analysis of the mean scores from the questionnaires to compare graphics to animations using a measure of significant difference and t test. The researchers compared still images to animations by calculating the difference of mean scores of students who viewed each of the two different treatments. These data were analyzed via t test and a significant difference was found. Researchers also collected mean scores from Section A of the experiment, but tallied the total number of correct responses on individual questions as well. In this study, the authors used the t test method to determine if there was a significant difference between mean scores of the animations and still images groups. The authors claim that p = 0.0004, which means that the mean results of the content related questions were significantly different between the two groups. The authors found that for both experiment 1 and experiment 2, when content was presented using decorative animations, students’ performance on the quiz questions was worse than their static graphic counterparts. The authors also supported their hypothesis that animations take up more working-memory capacity with their findings that students who viewed still images in Section B were able to correctly recall more images than those who saw GIFs.

**Research Discussion/Conclusions.** The authors of this study originally aimed to observe the seductive details effect of decorative animations and determine whether extraneous cognitive load explains such this impairment of comprehension and retention. The authors were able to conclude that students who viewed still images outperformed those who viewed animated images on content-based multiple-choice questions, whether it was for enzyme kinetics or human physiology content. The authors also concluded that students were better able to recall 10 images when they were still images, versus when they were animated GIFs. The results of the study also show that students felt like they had to use more mental effort when attempting to recall animated GIFs than those who viewed still images. The authors then conclude that viewing animations requires more cognitive processing than still images, thus impairing recall and comprehension. The authors of this article briefly mention previous research that claimed animations can be useful in reducing cognitive load for students learning science concepts in higher education, and they argue that these conclusions are due to the relevant nature of the animations in those studies. In this study, though, the authors focused on the effects of animations that do not lend value to the content but contain decorative visuals purely for enhancing appeal and engagement. With this, the authors imply that instructional designers should be careful to avoid using animations strictly for visual appeal, and only include them in instruction when it is relevant or useful for conveying information.

One limitation of the results and conclusions from this study is that the amount of supposed cognitive load that students experienced while viewing the visuals cannot be scientifically measured; the researchers collected data on this area using students’ own perception of their mental effort rated on a scale of 1-9. The researchers used appropriate statistical data to collect and compare a measurement of students’ cognitive load while viewing animations, but those data are not the most reliable form of measurement. So, I believe that the authors’ conclusions that animations increased cognitive load and that is the reason they impaired learning are weak assumptions to claim until additional measurements can be used. The authors also mention that due to their lack of collection of demographic information on the participants, they were unable to link participants scores to any factors that might have affected prior knowledge and their results on the questionnaires. Though the authors concluded that decorative animations impaired learning, they were unable to state the reason for why or how they do so, again because the level of internal cognitive processing is difficult to measure. The authors suggest that future researchers use heart-rate tracking and eye movement tracking to gauge a better understanding of students’ physical responses to decorative animations compared to still images.

**References Quality**. The authors of this article cite several sources that establish the need for their research. Previous studies on cognitive load theory and human learning provide the framework for this study, as extraneous details that are not relevant to the content can have an effect on the learning process. The authors also refer to previous literature about the growing prevalence of detailed graphics and animations in higher education curricula, which establishes the need to closely analyze the impact of such visuals on learning. Also included in this article is the analysis of studies that have evaluated the effectiveness of animations over static graphics, reporting that results are overall mixed among studies; some support the effective use of animations over graphics, while others claim there is no academic advantage of using animations.

**Overall Assessment**. I like this article because it has an opposing viewpoint than the rest of the articles I have reviewed for my research paper. The authors suggest that while some research shows that animations can be useful instructional tools in science courses, decorative and visually appealing animations do not always provide a benefit for learners. This article cites credible sources to establish the basis for the authors’ research, and uses their theories to determine the types of assessments that may support their hypotheses. However, my concern with this article is the lack of information about the visuals that were a major part of this experimental study. They do not specify anything further about the topic of the study, other than the words “enzyme kinetics” which are shown in Figure 2. Because of this vague explanation, it was difficult for me to understand the validity and reliability of the comparison between animations and still images. Then, the most important takeaway from the study is that animations may not always be useful instructional strategies for teaching science concepts, but the authors fail to discuss when animations can be useful. It is not clear what they mean when they state that animations included purely for visual appeal will impair learning. It would have been helpful to see or learn about an example of this type of animation. Additionally, I think the authors could have added another test group to the experiment, who views animations that are not merely decorative, but animations that are useful and informative for the concept. Then, the results could have provided a more definitive statement as to the difference between a useful animation and an animation that is potentially harmful to learners.

## Research Review Summary

### Introduction.

***Problem statement.*** The purpose of this instructional design applied evaluation project is to examine the use of instructional strategies that incorporate 3D animations in higher education biology and biochemistry and their effect on students’ comprehension, retention, and motivation with content involving complex molecular processes.

***Overall success of literature review search.*** Overall, my research was successful for obtaining a survey on the amount of research on 3D animations in higher education biology and biochemistry, and for suggesting that they have a positive effect on student motivation, comprehension, and retention. I found that there is plenty of literature supporting the need to study the effects of animations in biology courses, and the ability to obtain and utilize 3D animations is getting easier for instructors. Statistical data and open-ended feedback from the studies I reviewed made valid suggestions that partially answered my research questions, but a lack of data on the “how” and “why” animations effect learning left me with what I consider a slightly unsuccessful search.

***Limitations of literature review search.*** The specific focus of my research review limited the scope of articles that I included, thus the recommendations and implications of my findings were limited biology and biochemistry higher education. Additionally, research on the exact mechanisms by which animations affect motivation and improve comprehension and retention is only beginning, so the validity and reliability of some of the studies I reviewed were low. With this lack of research, my findings only partly answered my research questions in the ways that I had hoped.

### Summary of individual article findings.

***Article 1: Variation in External Representations as Part of the Classroom Lecture: An Investigation of Virtual Cell Animations in Introductory Photosynthesis Instruction.***  The authors of this article argue that static visuals with short-hand guides increase cognitive load, resulting in misconception of the content, especially for complex molecular processes involving several steps, such as photosynthesis (Goff et al., 2016). So, as external representations become more common for teaching biological concepts, the authors believe it is important to assess the use of animations for closing these comprehension gaps. Thus, the authors designed a study to assess the effects of their VCell animations on students’ comprehension of the content. They compared two treatments of a lecture on photosynthesis; one with VCell animations and the other with VCell static graphics. Their analysis of normalized gain scores from a posttest reflecting comprehension showed that there was a statistically significant treatment effect, as students who viewed animations outperformed those who viewed static visuals during their lecture. The results of this study suggest that instructional strategies that use 3D animations are more effective than those that use static visuals for promoting comprehension when teaching or learning complex biological processes with interacting steps.

***Article 2: Visualizing Protein Interactions and Dynamics: Evolving a Visual Language for Molecular Animation.*** Similar to the first article, the authors suggest that students and instructors struggle to teach/learn complex content at a high level of interconnected processes (Jenkinson and McGill, 2012). They emphasize that scientific advancements call for more sophisticated representations, and the assessment of the effect that varying levels of visual complexity has on learning is worth studying. Thus, the authors designed four versions of the same animation of a ligand-induced receptor dimerization and activation event each with increasing visual complexity and compared the four treatments at three time intervals. While they hypothesized that students who viewed less complex animations would perform better on posttest comprehension questions regarding basic concepts, this was not the case. Delayed posttest results suggest the opposite, as students who viewed more complex animations outperformed the other two groups on retention of basic concepts. Statistical data supported the hypothesis that more complex animations would foster greater comprehension of advanced concepts, but visual complexity did not have a significant effect on retention of advanced concepts. For my research, and for biology/biochemistry instructors, these results propose that instructional strategies that use 3D animations are most effective for learning advanced concepts and retaining basic concepts when the animations are more visually complex. The results from this study also suggest that 3D animations are more effective instructional strategies for learning complex biological processes with interconnected molecular reactions that traditional strategies.

***Article 3: The Value of Animations in Biology Teaching: A Study of Long-Term Memory Retention.*** The author of this article is an undergraduate biology professor who has conducted extensive research on the topic of animations as a supplement to lecture for complex biological processes (O’Day, 2007). The study in this article was a follow-up to his previous work that found that animations fostered greater understanding of molecular processes than static visuals. For this study, though, he decided to investigate the impact of animations on long-term retention of content due to the lack of current research on the topic. While O’Day did not use statistical significance to interpret the data, his comparison of mean scores from a posttest and delayed posttest supported his hypothesis that animations improved long-term retention. In two courses, one learning apoptosis and the other learning about cholesterol uptake, students who viewed animations remembered 83% and 79% (respectively) more than students who viewed static images with or without a legend. Though the sample for this study was limited to two of O’Day’s courses at one university, I thought that the author’s comparison of students’ retention to the standard “forgetting curve” was a unique and valuable way to interpret the data. The second hypothesis for this study came from Stith’s 2004 study that suggested students who view an animation instead of a static image will perform better on advanced questions. Though the data from O’Day’s cholesterol group partly supported this hypothesis, he concluded that the results of his study overall did not support Stith’s findings, and recommends that future researchers design their test instrument to more specifically test advanced versus basic concepts. For my research, this study suggests that instructional strategies that use 3D animations are more effective than those with static images for improving long-term retention of dynamic, complex biological processes.

***Article 4: Bio-Organic Reaction Animations (BioORA) Student Performance, Student Perceptions, and Instructor Feedback.*** The authors of this article designed a study to assess the effect of their animation software, BioORA, on students’ comprehension of enzymes, as well as the overall experience that students and faculty had using the software during lecture (Gunersel and Fleming, 2014). In three of four classes at Temple University, students performed significantly better on a comprehension quiz after their enzyme lecture using BioORA than they did on a similar quiz after a regular lecture on an enzyme. The authors stated that an important measure for the assessment of new instructional materials is student perception, so their survey for this study specifically pertained to students’ intrinsic interest in the content, attainment value, and their perceived ability. Qualitative analysis of the survey responses suggested that BioORA positively influenced students in those three areas; meaning, for my research, that animations led to greater student motivation compared to the regular lecture. While the interviews with the four instructors revealed some issues with the software – which is useful for improving the product, overall the faculty found BioORA to be a useful teaching and learning tool. After reviewing all feedback from the study, the authors emphasize that BioORA is most successfully implemented as a supplement to lecture and is a useful strategy for conveying complex molecular processes that cannot be directly observed. Thus, in response to my research, biology professors should employ instructional strategies that use 3D animations as a part of lecture instead of traditional lecture methods for teaching complex molecular processes.

***Article 5: Metabolism in Motion: Engaging Biochemistry Students with Animation.*** The authors of this article created a 3D animation that promotes a high-level understanding of metabolism that focuses on real-life applications and the dynamic interactions of pathways because previous research has shown that students struggle with these concepts (Long, Andreopoulos, Patterson, Jenkinson, & Ng, 2021). In their study, they collected responses from an optional survey after students viewed their animation to assess the effect of the animation on student engagement, confidence and relevance. While a tally of the responses suggested that the animation had a positive influence on students, the sample size was very small and limited to two courses at one university. Analysis of open-ended feedback suggested that the animation helped students to make big-picture connections between individual pathways and understand the application of metabolism to the real world, which were the goals for the animation. One significant limitation to this study is that all of the qualitative data pertaining to motivation (engagement, confidence, and relevance) were based on self-perceived measurements, rather than tangible data. The authors suggest that future studies should incorporate measurements such as that from eye-tracking software to quantify student attention and focus. Overall, this study suggests that instructional strategies that incorporate 3D animations may be useful when a high-level understanding of a complex network of processes is required, but the authors mention no comparative visual representation.

***Article 6: Decorative animations impair recall and are a source of extraneous cognitive load.*** The authors of this article claim that graphics and animations are becoming more popular in higher education biology courses, and the increasing accessibility to new technology only creates more opportunities for instructors to use it ineffectively (Pink and Newton, 2020). Because of this, they designed a study that compared comprehension and short-term retention of decorative animations to still graphics, assuming that decorative animations and GIFs will increase cognitive load thus impairing recall. Data from multiple choice posttests showed that students performed better on questions with a static graphic than questions with decorative animations. Similarly, students were able to recall static images more easily than GIFs after memorizing slides of 10 visuals of each. Immediately following the recall activity, students rated their mental effort trying to remember the items, which the researchers interpreted as perceived cognitive load. Comparison of static visuals and animations showed that students felt they used more mental effort to recall the animations, meaning the animations increased cognitive load and therefore may be the cause of impaired learning. While the results of this study may seem to suggest that animations can impair comprehension and retention, the authors failed to define “decorative” or suggest exactly how animations can be used ineffectively. Further research should better quantify cognitive load to determine the mechanism by which animations impair learning, so that educators and instructional designers can most effectively employ animations.

**Strengths of the overall findings.** Overall, my research review was successful in proving that instructional strategies that use 3D animations can be useful for teaching complex molecular processes in higher education biology and biochemistry. All of the articles included in my review were credible and most of the results were valid and used statistical significance to draw conclusions. The first part of my problem statement was to examine the current use of these instructional strategies, which I certainly achieved during the research and literature review. While looking for articles, I explored the surprisingly wide array of literature on the topic of animation in higher education science and learned that research on the topic started in the early 2000s but the majority of articles were published within the last five years. During the literature review, I realized that each article cited anywhere from 13-54 sources on previous research on the topic, as well as additional research that suggests the need for better representations of biology content.

The second part of my problem statement was to examine the effectiveness of instructional strategies that use 3D animations in higher education biology/biochemistry for improving student motivation, comprehension, and retention of complex molecular processes. My review did not examine how instructional strategies with 3D animations affect students’ motivation to learn complex molecular processes as thoroughly as I had hoped, but I was able to review the range of student feedback from most of the studies and gain insight into how well learners accept the new technology. For my other research question regarding the impact of animations on comprehension and retention, the review was partly successful in that it compared basic vs. advanced concepts, short-term retention vs. long-term retention, 3D animations vs. traditional methods, and decorative animations vs. simple graphics. I believe my findings were only partly successful because I had other potential answers in mind, as explained in the limitations section below. Nonetheless, my inclusion of a counter article in the review, by Pink and Newton (2020), was useful for determining when 3D animations may not be more effective and its opposing view offers credibility to my research.

**Limitations of the overall findings.** Though all of the articles included in my review were valid, the focused nature of my research narrowed my selection of studies to a specific type of content and learner audience. Each of the studies were only performed at one institution over the course of 1-2 years in specific biology and biochemistry courses, so the reliability of my findings is limited to learners of that specific demographic. Though four articles obtained statistical significance to support their conclusions, two of the articles relied on other data and learner feedback which were not as valid as quantitative results. O’Day (2007) was one of the authors who did not use statistical significance to support his conclusions, but I thought his quantitative comparison to the forgetting curve was valuable for supporting his hypothesis. Long and her colleagues (2021) only had 35 participants in their study and it lacked statistical analysis, but responses from their survey and open-ended feedback provided valuable insight into students’ perceived motivation with the content. Another limitation of their study worth noting was that the survey questions asked students to rate their perceived level of engagement, confidence, and relevance with the material. Perceived measurements are useful, but not as valuable as quantitative measurements. In a similar way, Pink and Newton (2020) used students’ own rating of mental effort after recalling graphics as an interpretation of cognitive load. Just as perceived measurements lead to weak conclusions, so too did poorly designed test instruments. Some of the articles mentioned low reliability of their test instrument and their authors believed that their test questions could have been more precisely designed to represent level of difficulty.

Long and her colleagues (2021) may not have had the most credible results, but theirs was the only one in my review that answered my research question regarding how animations affect student motivation. With this research question, I was looking for specific answers like “animations are more visually appealing to learners so they improve engagement,” or “animations improve motivation by providing learners with intrinsic reinforcement,” or perhaps that learners simply find animations more convenient or accessible than traditional methods. Additionally, I claimed that my review was only partly successful for answering when 3D animations are more effective for comprehension and retention. This is because I expected to find more specific answers such as ones that compared the different effects of animations:

* On males vs. females
* On students with different learner characteristics
* With or without narration
* Used during lecture vs. independently
* Used to introduce content vs. summarize content

**Specific recommendations from overall findings.**

The findings from my research suggest a few ideas as to how instructional strategies that use 3D animations affect students’ motivation with complex biological content. I found that 3D animations can improve motivation by increasing intrinsic interest, introducing relevance of the content for real-world applications, and increasing students’ confidence with the material. While the positive effect of animations on motivation certainly varies by students’ individual preference or learning style, most students felt that animations positively influenced their approach to learning the material. Though my review contained little statistical data for this research question, the sum of open-ended feedback from five of the articles provided a snapshot of students’ overall opinions of 3D animations, recommending that animations can improve motivation.

With my other research question, I proposed to investigate when instructional strategies that use 3D animations are more effective for improving comprehension and retention of complex molecular processes in higher education biology and biochemistry. The results of my review suggest that instructional strategies containing 3D animations are more effective than traditional strategies such as those that use static visuals, and more visually complex animations can be more effective than simple animations. I found that animations are more effective than their simple or traditional counterparts for improving comprehension and retention overall, but can be more effective for the immediate comprehension of advanced concepts and the long-term retention of basic concepts or declarative knowledge. My research suggests that instructors should implement instructional strategies that use 3D animations as a supplement to lecture when teaching complex molecular processes that have moving parts, are not directly observable, involve interconnected processes, or require a big-picture level of understanding. This is because animations provide a visual representation that fills the gaps in learning where traditional representations cannot. Finally, educators and instructional designers should not forget to carefully design their animations in a useful way. Decorative animations that are used simply for visual appeal may increase motivation, but they also have the potential to impair comprehension and retention of content.

**Implications for instructional applications and further research.** There are several implications for my findings to the field of instructional design. First, the studies I reviewed demonstrated the effectiveness of using instructional strategies that contain 3D animations in the higher education biology and biochemistry fields. This means that instructional designers and educators can confidently turn away from traditional methods and static visuals, and use 3D animations knowing that they can improve motivation, comprehension, and retention. As developing instructional technology offers new ways to represent content, educators should rely on previous research to learn how to use it most effectively and avoid impairing learning. The authors from the articles I reviewed also suggest that 3D animations are most effective when implemented as a supplement to lecture and instructional materials, so that the details and definitions can be learned first, and animations then help to draw a big-picture understanding. The findings of my research also imply that instructional strategies with 3D animations are useful and effective for conveying dynamic complex molecular processes that involve connected steps and cannot be directly observed, and when a big-picture level of understanding is desired. Specifically, my findings suggest that 3D animations can be effectively used for conveying photosynthesis, apoptosis, cholesterol uptake, enzyme kinetics, glucose and fat metabolism, and other interconnected molecular events such as molecular crowding, random molecular motion, and protein conformational change and stability.

Additional research on the topic has the potential to provide valuable insight for educators and instructional designers to understand exactly when, how and with whom animations are most effective for learning. As O’Day (2007) suggested, future research should continue to investigate the effect of animations on long-term memory retention and attempt to identify the cognitive process that cause this effect. Other articles suggested that future studies should contain carefully designed test instruments that assess comprehension and retention of different types of content to more precisely evaluate the effects of 3D animations. In other words, assessment questions should specifically test students’ ability to comprehend and retain basic concepts, advanced concepts, simple processes, complicated processes, or definitions. The results from my review also suggested that future researchers should also be careful to avoid self-perceived measurements when possible and use quantitative data and statistical analysis to draw conclusions. For instance, using eye-tracking software while students view an animation could be valuable proof that animations improve learning by signaling or drawing attention to specific parts of the content. Many of the articles in my review mentioned the impact that narration and on-screen text can have on the effectiveness of animations, thus future research should continue to investigate the effects of different forms of animation on motivation, comprehension, and retention. Future researchers should also evaluate the impact of learner differences such as spatial ability, prior knowledge, or learning preferences on the effectiveness of animations, so that educators can best implement 3D animation instructional strategies for their students.

### Discussion.

Though the literature review was only partly successful for answering my research questions in the way that I had hoped, my applied evaluation project was successful in many other ways. The literature search processes showed me that there is a surprising amount of research on animations in biology-related courses in higher education, which means that educators and instructional designers have plenty of resources to justify the use of instructional strategies that contain 3D animations. Five of the articles in my review focused specifically on my research topic, suggesting that 3D animations can be effective instructional strategies for teaching or learning complex molecular processes in higher education biology or biochemistry courses. Another major finding from my review is that these instructional strategies can elicit greater motivation, comprehension, and retention than traditional lecture methods and static graphics, which means the shift toward the use of technology and 3D animations is encouraged. Specifically, 3D animations have the potential to positively influence student motivation by establishing relevance, drawing attention, and increasing their confidence. They also can potentially improve student comprehension and retention by providing an alternative visual that more accurately illustrates interconnected or dynamic processes and provides a big-picture level of understanding. This means that biology educators and instructional designers can turn to 3D animations as a solution for unmotivated students or poor comprehension and retention when traditional methods are not working. Lastly, I found that the amount of impact, whether positive or negative, of 3D animations on learning can vary greatly depending on the animation itself. Aspects like visual complexity, narration, on-screen text, audio, and decorative features all play a role in the quality of the animation and its usefulness for instruction, therefore educators and instructional designers should develop their animations strategically based on the desired learning outcome. A comprehensive review of instructional animations in health sciences by Yue, J. Kim, Ogawa, Stark, and S. Kim (2013) suggested the same. They evaluated 430 medical animations for their adherence to principles of the cognitive theory of multimedia learning due to its extensive empirical support in the field of education. Principles such as the modality principle, redundancy principle, and signaling principle make suggestions about how to use narration, text, and visuals most effectively to enhance learning. They concluded that while most animations adhered to at least one of the principles, still the majority of animations had room for improvement and many even caused cognitive overload.

My counter article by Pink and Newton (2020) focused on cognitive load and the authors suggested that decorative animations increased it. A limitation to their conclusions, however is that they used self-perceived ratings of mental effort to measure the effect of animations on cognitive load, which are not as credible as quantitative data. A significant limitation to my review overall is that my research questions were not answered in the specific way I expected by most of the studies’ conclusions. Though it is useful to know that a 3D animation can have a positive effect on students, I believe it is much more useful to know what specific effect it has, when that effect occurs, and why it happens, so that instructional designers and educators can strategically implement animations at the most effective time. Hence, I had hoped to find data that explained specifically how 3D animations affect student motivation, for instance, eye-tracking measurements to track learners’ attention and focus on the material. I similarly expected to find hypotheses and conclusions about the specific mechanisms that cause animations to have an effect on comprehension and retention. I hunted for these types of conclusions during my literature search and was unsuccessful to find any, but I do not feel that I was at fault. Though research on 3D animations in biology and biochemistry higher education is plentiful, educators and instructional designers only recently began investigating the mechanisms as to how or why animations might improve learning, so the answers that I was looking for during my research have yet to be studied. Thus, any future research on the topic of 3D animations as effective instructional strategies for improving motivation, comprehension, or retention should aim to observe the effect of the strategy and then identify the mechanism by which the effect occurs.

My intention to investigate instructional strategies with 3D animations only for teaching complex molecular processes limited the scope of articles I reviewed; thus, the conclusions of my review can only be applied to biology and biochemistry higher education. So, to extend the implications of my research and build a stronger argument for the use of 3D animations in education overall, future research should compare its effectiveness for different types of content; i.e., biology vs. non biology, complex processes vs. simple processes, or processes vs. definitions. Future research should also include a wider range of demographics in the sample so that researchers can evaluate the individual effects of 3D animations on learners with different characteristics such as learning preference, prior knowledge, age, sex, ethnicity, or environment. Some of the articles in my review contained suggestions for when instructors should use their animations and what kind of additional materials should supplement the animation for the most effective learning. Based on their conclusions, I think that future research should also evaluate the effectiveness of 3D animations when they are implemented in different ways so that instructors can strategize what is best for their lecture. I suggest that researchers implement animations at different time points for various purposes, such as before lecture to introduce content, during lecture to break up lengthy content, after lecture to summarize content, as homework to reinforce content, or as a quiz to assess comprehension, and then evaluate their impacts on learning.

### Conclusions.

For this literature review, I first set out to examine the current and studied uses of instructional strategies that contain 3D animations to teach molecular processes in higher education biology and biochemistry courses. The initial act of searching for literature to review provided a snapshot of current literature on the topic of animations in science and medical education, and there was much more content than I had expected. With my selection and review of articles, I intended to identify the overall effect and mechanisms by which instructional strategies with 3D animations impact student motivation, comprehension, and retention for learning complex molecular processes in higher education. Overall, I found that 3D animation instructional strategies can positively impact these three aspects of learning especially when compared to traditional methods, static graphics, or simpler visual representations. I found that learner motivation is affected by the animation’s ability to draw attention and establish relevance and confidence, but the specific mechanisms of how an animation can do this better than other instructional strategies is not yet fully understood. In a similar way, I found that visual complexity, narration, on-screen text, and decorative features can have positive or detrimental effects on learning, and 3D animations can potentially elicit better understanding of different types of concepts, i.e. definitions or abstract ideas, but the mechanisms as to how animations cause these effects have not been determined. Though the cognitive theory of multimedia learning suggests that cognitive load plays an important role in comprehension and retention, the adherence of biology and biochemistry animations to the principles of this theory has not been extensively studied, thus research has not been able to conclude that CTML is the main explanation for the observed effects of animations on learning. Besides, even if future research focused on linking the impact of 3D animations to cognitive load, researchers would struggle to identify the exact mechanism of impact because cognitive load is difficult to measure quantitatively. Another major finding worth noting is that instructional strategies with 3D animations are useful in higher education for teaching complex molecular processes that involve dynamic or interconnected parts and reactions at a high-level. In fact, many of the selected animation topics in the studies I reviewed derived from recent literature in biology education that identified the most frequently misunderstood concepts and processes. This finding offers useful advice for instructors and designers in the higher education biology or biochemistry field: identify complex molecular processes that are difficult to convey and recurrent struggle areas within your curriculum, then consider implementing instructional strategies with 3D animations to improve the learning outcome. Still, this suggestion is specific to higher education biology and biochemistry because my review did not include an analysis of other subject areas, thus the applicability of my findings is limited. Moreover, my narrow focus for this review limited the variation in learner demographics of the six studies so my findings are not necessarily applicable to the field of education as a whole. This was not my goal anyway; I chose to focus on molecular processes for my review because I would like to develop molecular animations in my future as an instructional designer. When I first decided on my research topic, I wasn’t sure if I would find enough articles that particularly addressed 3D animations of molecular processes, so I anticipated having to broaden the topic to scientific concepts. Satisfyingly enough, I found plenty of studies relating to molecular processes, so I was able to maintain my preferred area of focus. Originally, I intended to examine the effectiveness of 3D animations for improving engagement and understanding, but as I thoroughly reviewed each article and its hypothesis, I refined these terms accordingly. I shifted to motivation (as it includes engagement) and I divided understanding into comprehension and retention because these specific outcomes were addressed by many of the authors, plus they made my review more concise.

What I learned during my exploration of instructional strategies that incorporate 3D animations of molecular processes in higher education biology and biochemistry can be summarized in general terms. The overall effectiveness of an instructional strategy is dependent on many variables, including learner characteristics, audiovisual details of the material, complexity or nature of the material, how the strategy is implemented, and the desired learning outcome. I expected these findings, however I did not expect to discover the lack of research on the mechanisms by which 3D animations cause an effect on students, and this was not the only unexpected piece of information. The articles that I reviewed were very thorough to establish the need for their research, which answers a question I hadn’t initially considered; why should instructional designers use 3D animations in higher education biology and biochemistry? The sources cited in the articles suggest that previous research in higher education biology and biochemistry courses as well as scientific research encourage the use of 3D animations and support the need to study the effective use of them. Cited research from the articles indicated that visual representations are becoming more popular for teaching biological processes as new instructional technology is developed, so the study of the effect of various technologies on learning is becoming pertinent. O’Day’s use of PowerPoint and Camtasia to develop his own animations also came as a surprise, because he insinuated that instructors can create custom animations more easily as technology advances and becomes readily available (O’Day, 2007). This supposed feasibility to develop animations certainly contributes to the argument in support of evaluating 3D animations for use in higher education. Advancements in scientific research also justify the need to examine new instructional strategies, as more complex details are discovered and need to be taught across the scientific community. Then with these struggles identified, many educators are shifting toward learning goals with a high-level of understanding, rather than rote memorization of details. Many of the authors from my review stated that this shift of learning goals and the awareness of common problem areas further support the need to study the effectiveness of instructional strategies, especially those that use 3D animations. This finding, of course, offers a significant contribution to the existing literature because it justifies the need to both use and study the effects of 3D animations in higher education. My study was an overall review of literature on molecular animations and my finding that the exact mechanisms that explain the effects of these animations are not yet well understood provides context for anyone new to the topic. In other words, someone who researches the effectiveness of 3D animations in higher education biology might interpret the lack of explanation for its effects as nonreliable or untrustworthy. But, the findings from my review could offer them perspective and insight about the current struggles with this research topic overall. With this, my findings also suggest the fact that learning and motivation theories can be applied to instructional strategies that use 3D animations in order to develop and implement animations most effectively. All things considered, my review supported the general claim of existing literature: that 3D animations can be useful instructional strategies for teaching complex molecular processes in higher education biology-related courses, and they can have a positive influence on motivation, comprehension, and retention if used appropriately.

Contributing to the development of 3D molecular animations is my ultimate career goal, so I was pleased to find that so many educators are already implementing such instructional strategies into their curricula and many believe they positively affect learning. Since I found that the explanations for how and why animations affect students are still lacking, I would be sure to improve upon previous research if I were to conduct my own future studies. I learned that a larger sample size with varying demographics can improve the credibility of my research, and tracking learner characteristics as they influence students’ responses to the animations. I would also attempt to evaluate the difference in effectiveness for various types of content, like rote memorization or high-level concepts, and for various methods of implementation, such as to introduce content or as an at home activity. My literature review made it clear that there is plenty more research to be done on the use of 3D animations in education, and I hope to contribute to that someday. Until then, I can apply the findings from my review to any of my future instructional design projects. I now will consider using instructional strategies with 3D animations for conveying any type of dynamic, complex, interconnected processes where students struggle to understand the big picture. I learned that I should design animations and any type of multimedia instruction with intention, as to avoid decorative visuals while also including the appropriate amount of visual complexity for the type of content and learning outcome. As for my overall instructional design practices, my review reminded me how much of an impact instructional strategies and multimedia can have on students. Thus, I will be sure to consider which instructional strategy is best for the type of learners and content to best enhance learning. The implementation of instructional strategies is equally as important, so I will be sure that multimedia is supplemented when necessary and selected strategies are justified.

Throughout the process of conducting this review, I learned that literature reviews can provide the researcher with an overview of current literature, even if they only focus on a few articles in the end. I found that just by viewing the cited sources in six articles, I was able to understand just how much research on animations in education there was. Additionally, when finding specific articles pertaining to my research became difficult, I was able to use some of the cited articles from one reliable paper as additional sources relevant to my research. My research review had a very narrow focus, so my conclusions were only applicable to a specific group in the field of education. Because of this, I learned that research in the instructional design and technology field can be tricky, since much of it is specific to certain demographics or topics. Thus, to make general conclusions about which instructional strategy is best, research must include samples of various types of learners and demonstrate similar findings.

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